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# Design and construction of a computer controlled microthermcouple probe for the study of buoyant jets.

Matoushek, Ronald John

Monterey, California. Naval Postgraduate School

# NAVAL POSTGRADUATE SCHOOL

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# THESIS

DESIGN AND CONSTRUCTION OF A COMPUTER CONTROLLED MICROTHERMOCOUPLE PROBE FOR THE STUDY OF BUOYANT JETS

by

Ronald John Matoushek

September 1984

Thesis Advisor: William G. Culbreth

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#20 - ABSTRACT - (CONTINUED)

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Design and Construction of a
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by

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requirements for the degree of

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A computer-aided data acquisition system was developed and a microthermocouple probe constructed to obtain thermal distributions in turbulent buoyant jets exposed to a cross-flowing ambient fluid. The system performed high speed temperature measurements as a microthermocouple probe was automatically traversed through a sequence of preprogrammed positions under the control of a microcomputer. Operability of the apparatus was demonstrated by measuring temperature distributions in planes perpendicular to the streamwise axis of jets from which contour plots of temperature were generated. Using temperature distributions along with velocity distributions allow buoyant jet characteristics to be computed, including the entrainment rate of ambient fluid, jet trajectory, and heat transfer to the ambient. The experimental technique is discussed and temperature contour plots for a jet at various planes are presented.

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## NOMENCLATURE

| | |
|---|---|
| $A_{ij}$ | Incremental Cross-Sectional Area in the Temperature Matrix |
| $B$ | Jet Half-width |
| $b$ | Normalized Jet Half-width |
| $c_p$ | Specific Heat |
| $D$ | Diameter of the Jet at the Nozzle |
| $D_{AB}$ | Binary Mass Diffusion Coefficient |
| $F$ | Densiometric Froude Number |
| $g$ | Acceleration of Gravity |
| $\dot{Q}$ | Heat Transfer Rate from the Jet to the Ambient Fluid |
| $R$ | Ambient-to-Nozzle Flow Ratio |
| $R_a$ | Length of the Probe Arm |
| $r$ | Radial Distance from the Center of the Jet |
| $r_p$ | Length of the Probe |
| $S$ | Schmidt Number |
| $s$ | Streamwise Coordinate Along the Jet Centerline |
| $T$ | Normalized Jet Temperature |
| $T_a$ | Ambient Fluid Temperature |
| $T_{ij}$ | Jet Temperature Within the Temperature Matrix |
| $T_m$ | Centerline Jet Temperature |
| $T_n$ | Nozzle Temperature |
| $T_p$ | Jet Temperature As Measured by the Probe |
| $T(r)$ | Temperature Within the Jet at a Radial Distance (r) from its Center |

| | |
|---|---|
| $U_m$ | Centerline Velocity of the Jet at the Nozzle |
| $U_o$ | Discharge Velocity of the Jet |
| $U(r)$ | Velocity within the Jet at a Radial Distance "r" from its Center |
| $U_{ij}$ | Jet Velocities Corresponding to Locations within the Temperature Matrix |
| $u$ | Normalized Centerline Velocity |
| $\alpha$ | Entrainment Coefficient; Offset Angle of the Probe Arm |
| $\beta$ | Offset Angle of the Probe Mounting Bracket |
| $\gamma$ | Probe Angle of Deflection from Horizontal |
| $\theta$ | Local Angle of Inclination from Horizontal of the Jet Streamwise Axis |
| $\lambda$ | Spreading Ratio |
| $\nu$ | Kinematic Viscosity |
| $\rho$ | Density of the Jet Fluid |
| $\rho_a$ | Density of the Ambient Fluid |
| $\rho_{ao}$ | Density of the Ambient Fluid at the Nozzle Exit |
| $\rho_m$ | Density of the Jet at Centerline |
| $\rho_{mo}$ | Centerline Density of the Jet at the Nozzle |
| $\phi$ | Angle of Inclination of the Data Plane from Horizontal |

# I. INTRODUCTION

Buoyant jets are very common in nature. We see them in the form of exhaust gases emitted from smoke stacks of refineries, mills and ships. We see them in the form of heated waste water expelled into the sea from power plants and from the main propulsion condensers in steam driven ships and submarines. It is no wonder that the fluid mechanics and heat transfer characteristics of buoyant jets have been of interest to environmental, civil and mechanical engineers for decades. To evaluate their ecological impact, and of most recent interest, to harness buoyant jets as a means of detecting military targets and guiding weapons, it is necessary to develop models which accurately predict their trajectory and decay.

Most studies to date have dealt with buoyant jets rising through a quiescent ambient fluid; however, in nature most problems involve flowing ambient fluids. Relatively little experimental work has been done with buoyant jets in cross-flow and, according to Hilder [Ref. 1], the trajectories of jets and the entrainment rates of ambient fluid predicted from previous work do not agree well with one another. Most mathematical models of buoyant jets in crossflow assume Gaussian profiles for velocity and temperature. Nickodem [Ref. 2] has shown through experiments that in fact, the

Gaussian profiles of velocity are altered by crossflow. This leads one to suspect that the same may be true for the temperature profiles.

The objective of this work was to develop a system to thermally map a buoyant jet in crossflow. Then, by measuring both velocity and temperature distributions, improved computations of entrainment, trajectory and heat transfer characteristics of jets can be made thereby giving rise to more accurate models.

## II. BUOYANT JETS DISCHARGED TO A CROSSFLOW

### A. PROPERTIES OF BUOYANT JETS

A buoyant jet is characterized by a momentum and a density differential between the jet and its surrounding ambient resulting from a variation in temperature and/or fluid concentrations. Therefore, fluid motion in the jet is governed by both inertial and buoyant forces. The non-dimensional ratio of these forces, known as the densiometric Froude number, provides an important quantitative measurement of jet characteristics and is shown below.

$$F = \frac{U_o^2}{gD(\rho_a - \rho_o)/\rho_o}$$

where $U_o$ is the jet's discharge velocity, g is the acceleration of gravity, D is the discharge diameter of the jet, $\rho_a$ is the density of the crossflowing ambient and $\rho_o$ is the density of the jet fluid at its point of discharge.

The Gaussian velocity and temperature profiles assumed by most models of buoyant jets are very similar. Velocity behavior is given by:

$$U(r) = U_m \exp(-r^2/B^2)$$

where $U_m$ is the centerline velocity, r is the independent variable and a radial distance from the centerline of the jet, and B is defined as nominal jet halfwidth. As r approaches B, velocity decays to $(1/e)U_m$ [Ref. 3]. Similarly, temperature behavior is given by:

$$T(r) = T_m \exp(-r^2/\lambda^2 B^2)$$

where $T_m$ is the centerline temperature, r and B are defined the same as above and $\lambda$, a spreading ratio, is the inverse of the turbulent Schmidt number (S). S is defined as the ratio of the molecular momentum and mass diffusivities and is equal to $\nu/D_{AB}$ where $\nu$ is the kinematic viscosity and $D_{AB}$ is the binary mass diffusion coefficient associated with substances A and B [Ref. 4]. Although $\lambda$ varies inversely with the Froude number, the change is very slight, and in the case where substances A and B are both water, $\lambda$ is slightly greater than 1. Hirst [Ref. 3] found $\lambda$ to vary between 1.16 at F = 0 to 1.11 at F = infinity. The net effect then, is a more gradual temperature decay than was found with velocity.

Most buoyant jet models consider the entrainment of the ambient fluid into the jet and are based on relevant conservation equations of mass, momentum and energy. In conservation of mass, the downstream change in total mass of the jet is equated to the mass of the entrained fluid. The conservation of momentum must consider both vertical and horizontal contributions. Changes in vertical momentum are equated to the buoyant forces while changes in the horizontal momentum of the jet are equated to the horizontal momentum of the entrained fluid. The conservation of energy involves energy changes resulting from variations in the ambient temperature as caused by the jet. Hilder [Ref. 1] developed the following governing equations in non-dimensional differential form.

CONTINUITY
$$\frac{d}{ds}(u_m b^2) = 2\alpha b[|u_m - R\cos\theta| + a_3 R\sin\theta]$$

HORIZONTAL MOMENTUM
$$\frac{d}{ds}(u_m^2 b^2 \cos\theta) = 4R\alpha b[|u_m - R\cos\theta| + a_3 R\sin\theta]$$

VERTICAL MOMENTUM
$$\frac{d}{ds}(u_m^2 b^2 \sin\theta) = \left(\frac{\rho_a - \rho_m}{\rho_{ao} - \rho_{mo}}\right)\cdot\frac{2\lambda^2 b^2}{F^2}$$

ENERGY
$$\frac{d}{ds}\left(u_m T\cdot\frac{\lambda^2 b^2}{(\lambda^2+1)}\right) = \frac{\Delta t_a}{ds}\{u_m b^2\}$$

## B. FLOW REGIMES

The jet passes through several regimes as it travels from the nozzle through the ambient. The three regions most frequently referred to are shown in Figure 1. They are the zone of flow establishment, the zone of established flow and the far-field zone [Ref. 3]. In the zone of flow establishment, the velocity and turbulence profiles transform from the conditions within the nozzle to a free turbulent flow condition. It is in this region that the jet begins to mix with the ambient fluid; however, the flow is still more

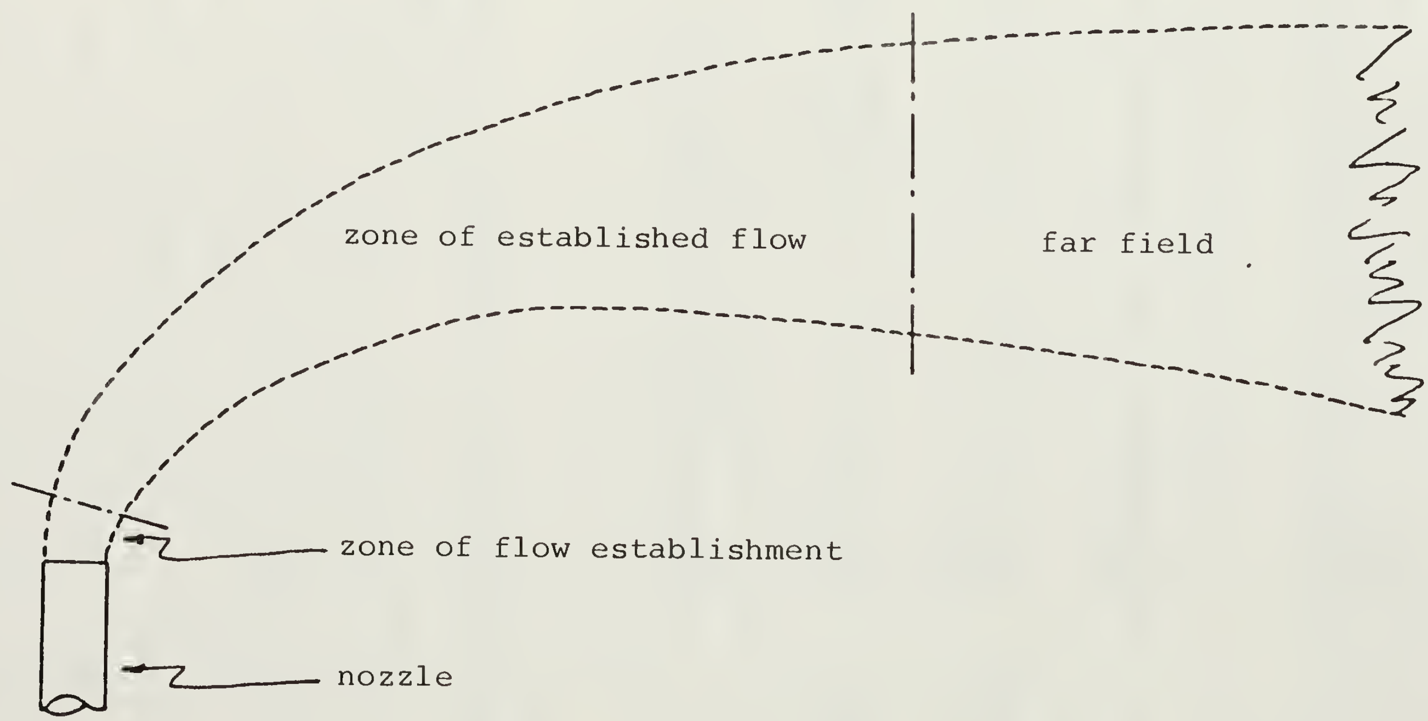



Figure 1. Typical Flow Regions in a Buoyant Jet

strongly influenced by the nozzle discharge conditions than by the ambient. When the turbulent mixing has reached the centerline of the jet, the zone of established flow is said to begin. In this region, the profiles have assumed their free turbulent shapes. Now the flow is governed by the jets' momentum and buoyancy as well as by the condition of the crossflow. The far field zone is defined as that region in which jet momentum is depleted and the jet fluid is convected and diffused by the ambient currents and turbulence.

## C. EFFECTS OF CROSSFLOW

At the immediate exit of a cylindrical nozzle, a vertically discharged buoyant jet has a nearly uniform velocity distribution and has the same cross-sectional shape as the nozzle itself. The velocity gradient between the jet and the crossflowing ambient creates longitudinal shear stresses at the jet's sides, a positive pressure region immediately upstream and a negative pressure region immediately downstream of the jet. This results in the deflection of the jet's trajectory in the downstream direction (Figure 2), the creation of counterrotating vortices at the jet's outer edges and the deformation of the original circular cross-sectional shape into the form of a kidney. As the streamwise axis of the jet approaches the direction of the crossflow, these effects become progressively less pronounced.

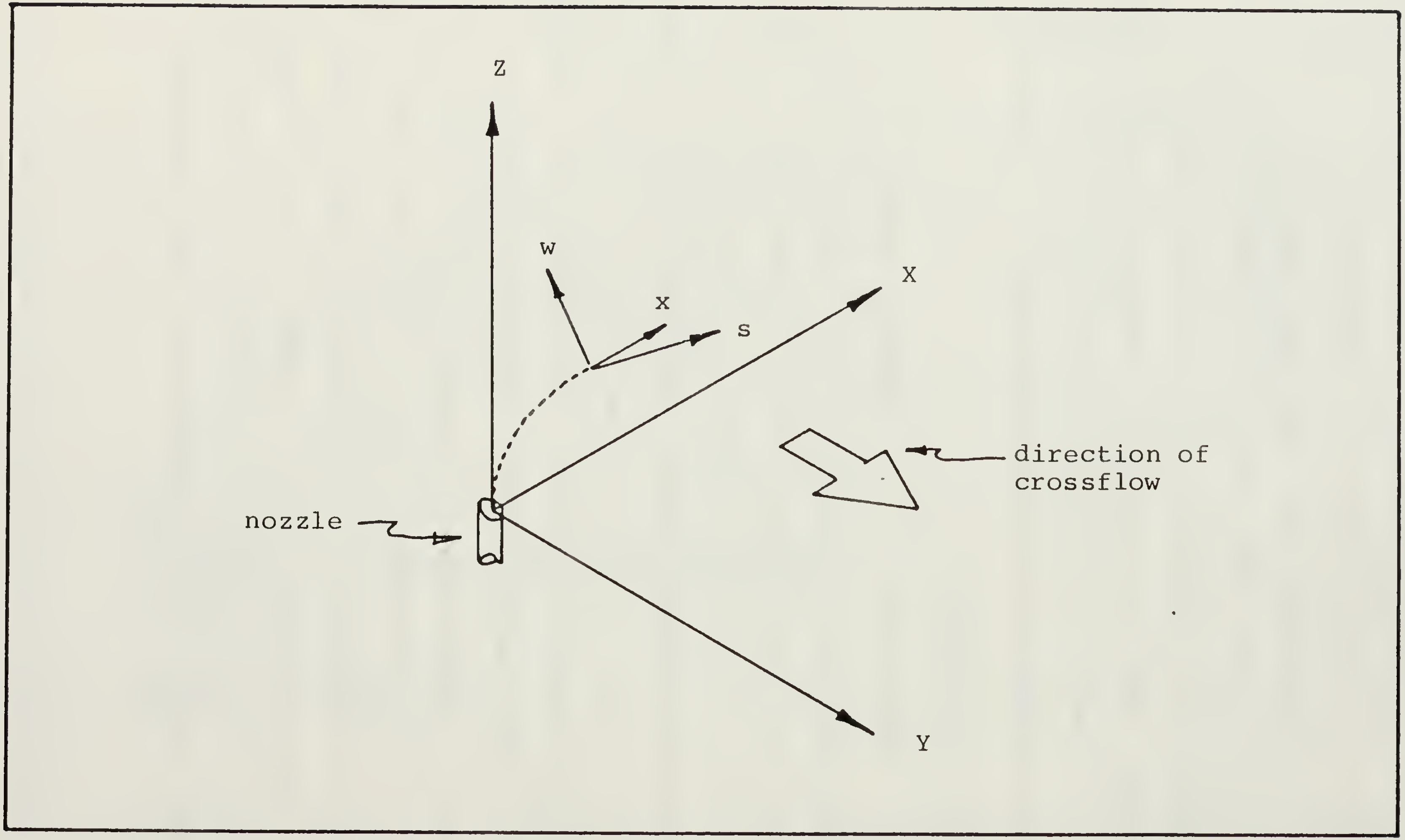



Figure 2. Coordinate System for a Buoyant Jet

## III. EXPERIMENTAL APPARATUS

### A. SYSTEM OVERVIEW

A surplus milling machine was configured with synchronous drive motors interfaced with a microcomputer that automatically positioned its bed. It was used as a three-dimensional positioning platform in the same manner as in the laser Doppler velocimetry work undertaken by Nickodem [Ref. 2]. The milling machine was placed adjacent to a rectangular plexiglass flume through which the crossflowing ambient fluid flowed. A vertical nozzle was installed in the base of the flume to provide the jet. A temperature probe was suspended through an opening in the top of the flume above the nozzle by an arm attached to a base mounted on the milling machine bed as shown in Figure 3. As the probe was automatically traversed through a series of preprogrammed positions across the jet, temperature data was automatically sensed and stored at high speeds by the computer.

### B. CROSSFLOW SYSTEM

As illustrated in Figure 4, the crossflow circulation pump took water from the cylindrical 248.8 l (65.7 gal) reservoir shown in Figure 5 and discharged through 5.076 cm (2 in) diameter tubing into a cylindrical flow settling chamber 30.46 cm (12 in) in diameter and 60.91 cm (24 in) tall located within the 60.91 cm × 60.91 cm × 88.83 cm

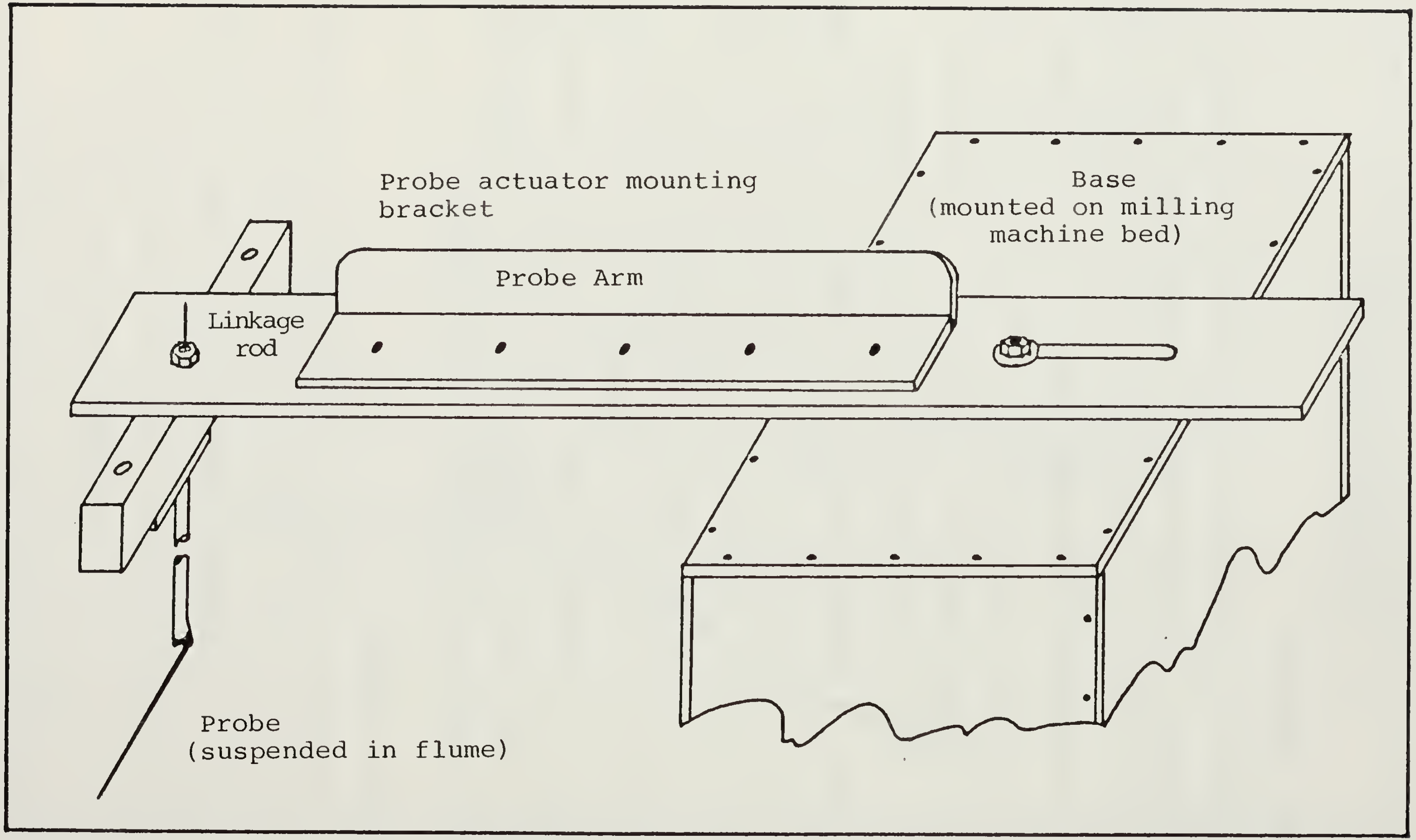
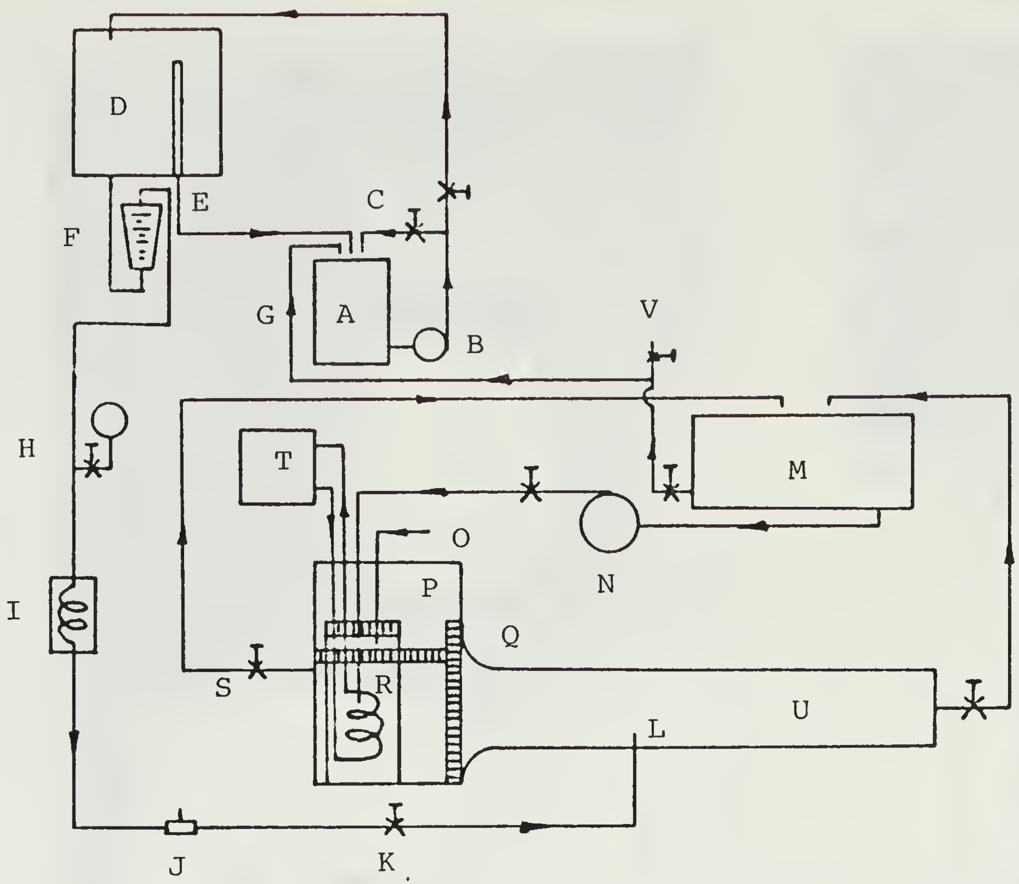



Figure 3. Probe and Traversing Mechanism




A. Jet flow pump reservoir
B. Jet flow pump
C. Jet flow pump recirc
D. Head tank
E. Head tank overflow
F. Rotometer
G. Make-up
H. Dye injection system
I. Heater
J. Thermocouple junction
K. Jet flow control valve
L. Nozzle
M. Crossflow pump reservoir
N. Crossflow pump
O. Fill/Make-up
P. Inlet chamber
Q. Flow straighteners
R. Flow settling chamber
S. Crossflow recirc
T. Cooler
U. Flume
V. Drain

Figure 4. Crossflow and Jet Loop Piping Diagram

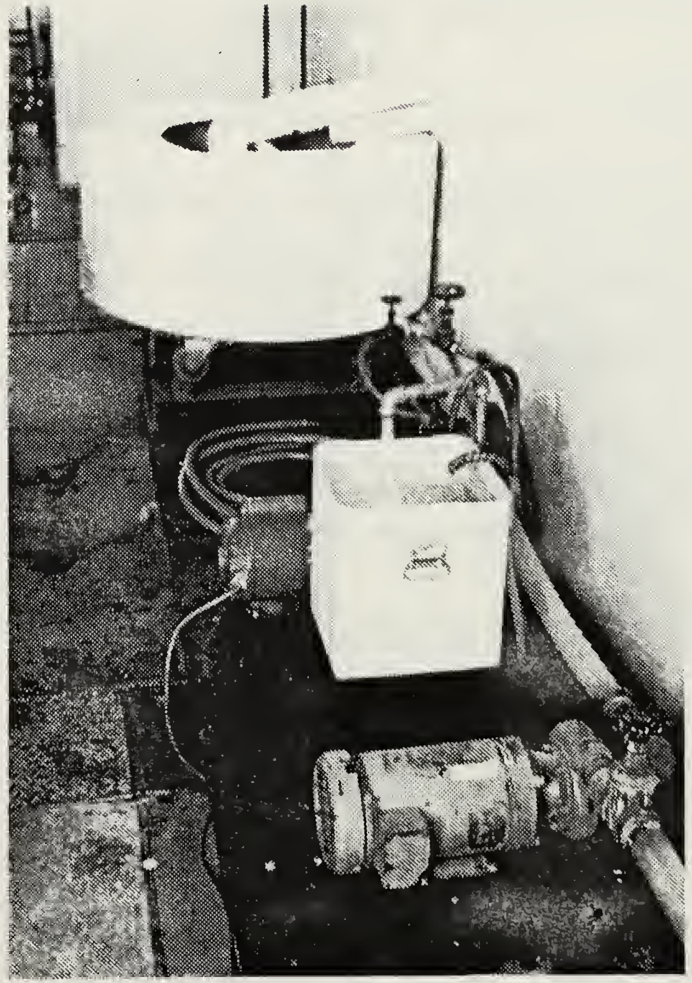


Figure 5. Flume Circulation and Jet Loop Pumps

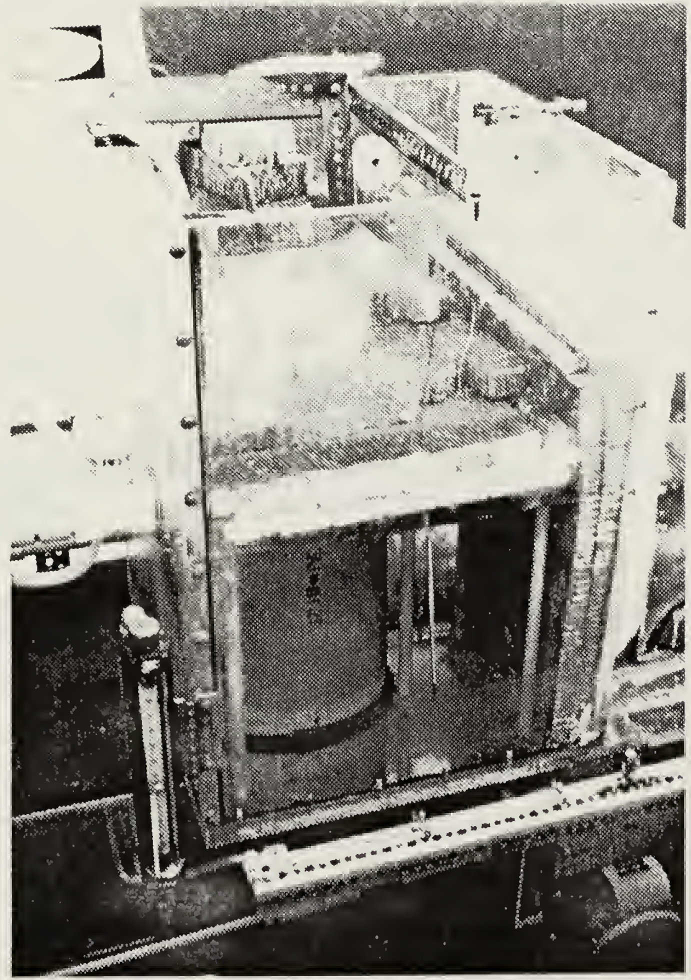


Figure 6. Inlet and Flow Settling Chambers

(24 in $\times$ 24 in $\times$ 35 in) inlet chamber shown in Figure 6. The settling chamber was sealed at its bottom so that the water spilled from its top into the inlet chamber through honeycombed flow straighteners to reduce turbulence and evenly disperse the flow. To further reduce turbulence, the flow was broken by another stack of honeycombed flow straighteners and a layer of fiberglass filter material located immediately above the normal operating water level. The flow next entered a 24.4 cm $\times$ 32.39 cm $\times$ 182.9 cm (9.625 in $\times$ 12.75 in $\times$ 72 in) flume shown in Figure 7 through a vertical section of the same honeycombed material mentioned above. To avoid inadvertent spillage over the sides of the flume during system start-up, a 5.076 cm (2 in) diameter overflow pipe was located in the inlet chamber. During normal operation, a gate valve in this piping was closed. The flow left the flume through a 7.614 cm (3 in) diameter pipe at its end and re-entered the crossflow circulation pump reservoir. A gate valve located in this piping and shown in Figure 8 was used to regulate the water level and flow velocity in the flume. The optimum adjustment of this valve was determined by trial and error to be closed two turns from its fully open position. Either a globe or ball valve would have been more appropriate for this purpose; however, neither was readily available, so the gate valve was used. The bracket shown at the base of the flume in Figure 8 maintained alignment between the flume and the milling machine. The water

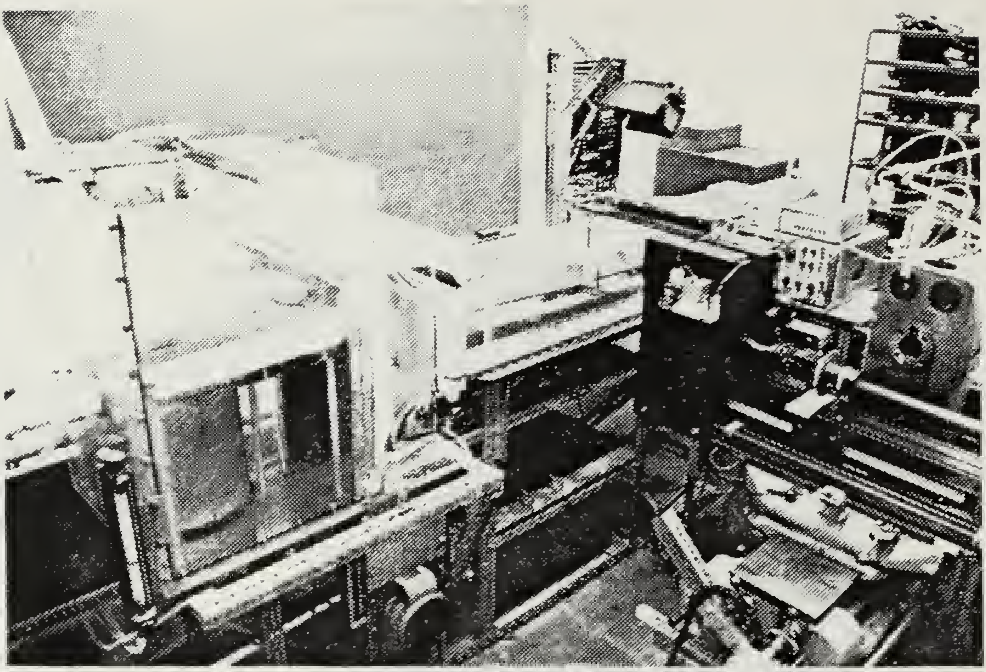


Figure 7. Flume Arrangement

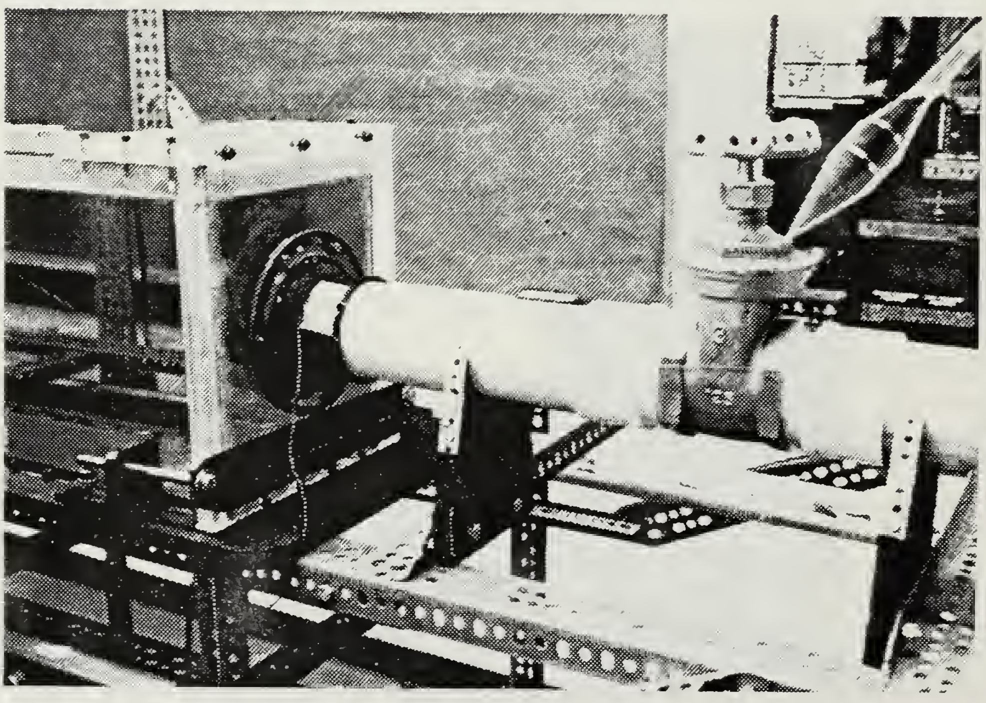


Figure 8. Flume Discharge Piping

in the flume was gradually heated by repetitive circulation through the crossflow pump and by the addition of the heated water from the jet. To maintain a constant temperature crossflow, cooling water from a refrigerated bath shown in Figure 9 was circulated through a coil of 1.269 cm (.5 in) diameter copper tubing located in the flow settling chamber. Also, fresh water was added at the flow settling chamber as an equal amount was drained from the crossflow pump reservoir through a 1.269 cm (.5 in) diameter pipe. Crossflow temperature was monitored by a Type-T thermocouple located in the inlet chamber.

## C. JET SYSTEM

In reference to Figures 4 and 5, the jet flow pump circulated water from a rectangular 26.27 l (6.94 gal) reservoir and discharged through 1.26 cm (.5 in) diameter tubing to a 33.0 cm $\times$ 50.8 cm $\times$ 54.6 cm (13 in $\times$ 20 in $\times$ 21.5 in) head tank (Figure 10). The amount of flow to the head tank was regulated by a globe valve. Due to a low flow rate to the head tank, water was also recirculated back to the reservoir in order to maintain sufficient flow through the jet pump to prevent overheating it. A constant water level was maintained in the head tank by a stand pipe which allowed overflow back to the reservoir. Sufficient flow into the tank was maintained to make sure that it slightly overflowed continuously. Water drained from the bottom of the head tank through 1.26 cm (.5 in) diameter tubing and passed

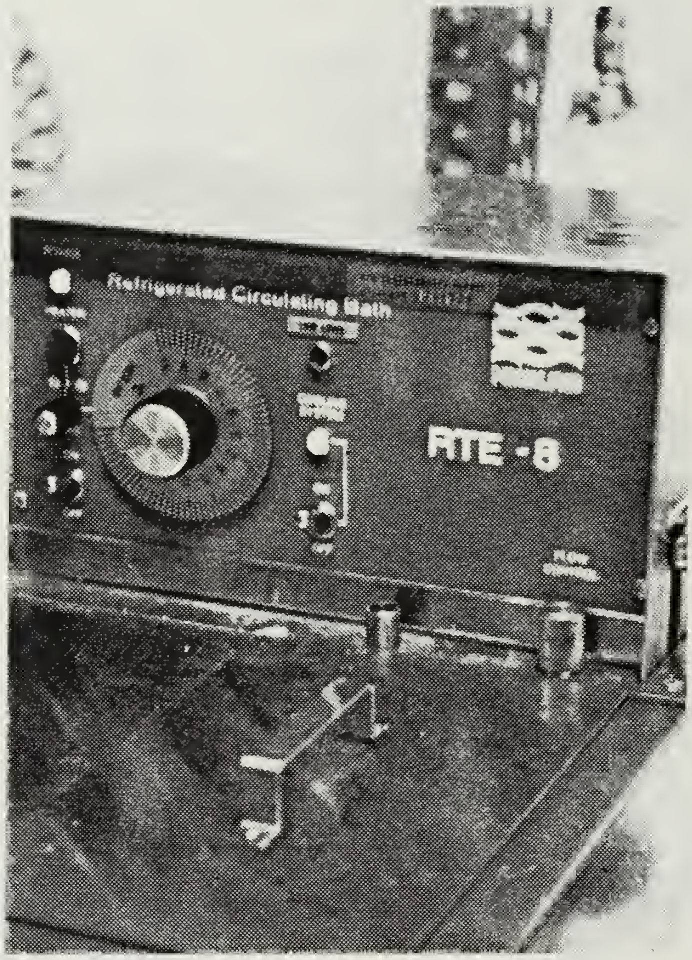



Figure 9. Refrigerated Bath

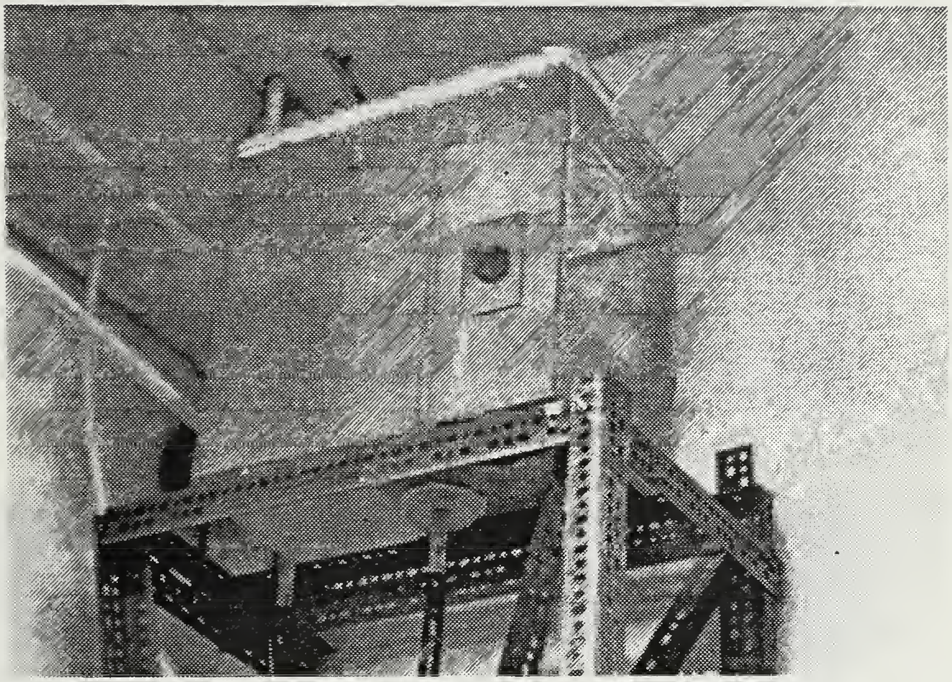


Figure 10. Head Tank

through a rotometer, a .95 cm (.375 in) tubing reducer, a dye injection system (Figure 11), a water heater (Figure 12) consisting of approximately 6.09 m (20 ft) of .95 cm (.375 in) diameter copper tubing coiled in a heated bath and finally a 7.144 cm (.28125 in) nozzle which discharged into the bottom of the flume. Flow was controlled by pinching the tubing between the heater and the nozzle with surgical clamps. Drainage from the crossflow reservoir discussed in Section III.B was used to replenish the jet reservoir. The dye injection system, used in photographing the jet, was located approximately 8.23 m (27 ft) upstream of the nozzle to minimize any disturbance to the jet that it might have caused. The majority of this distance was taken up by the heating coil mentioned above. The vertical distance between the top of the stand pipe in the head tank and the tip of the nozzle in the flume was 2.2 m (86.5 in) which equated to 21.56 KPa (3.127 psig). Jet flow temperature was monitored by a Type-T thermocouple located within the jet flow tubing approximately 1.167 m (46 in) from the nozzle.

## D. TEMPERATURE PROBE

Measuring temperatures in a buoyant jet with a thermocouple is intrusive. To reduce the probability of distorting results, steps were taken to minimize the cross-sectional area of the temperature measuring device as seen by the flow of the jet. A .0254 mm (.001 in) diameter Type-E microthermocouple was selected. The suspension device for the

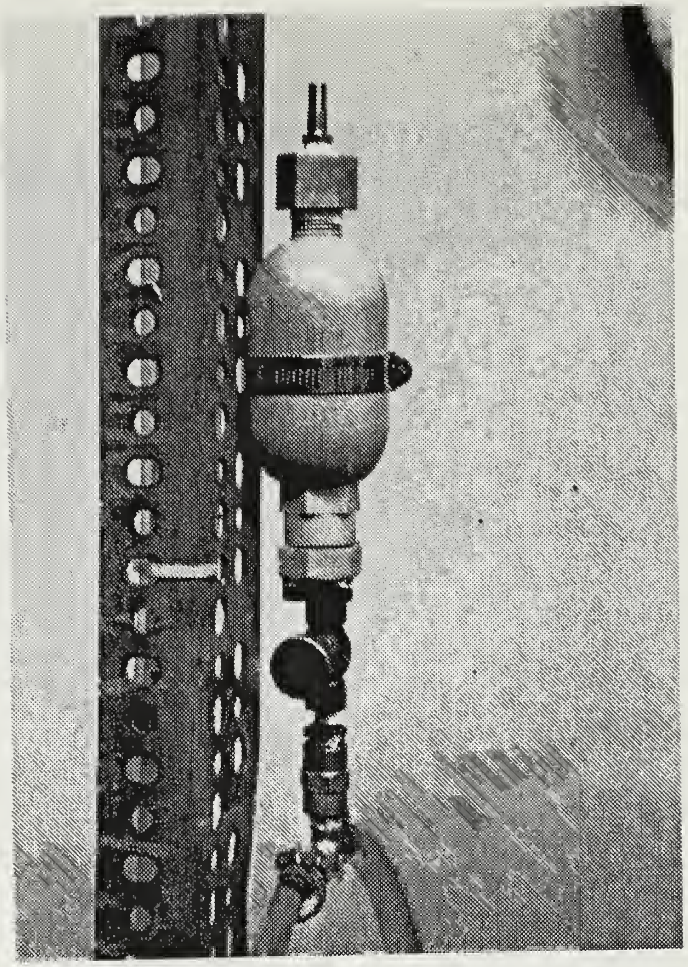


Figure 11. Dye Injection System

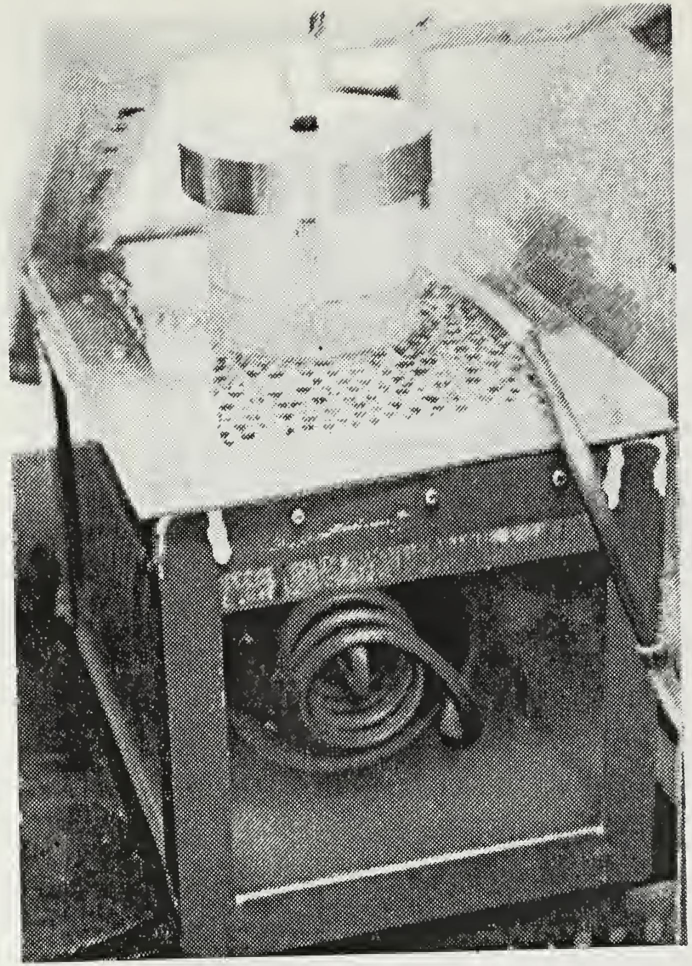


Figure 12. Jet Heater

microthermocouple had to be rigid and have a small cross-sectional area, for reasons discussed above, as well as be an electrical insulator to prevent interference with the thermocouple performance. A glass annulus approximately 1.45 mm (.057 in) in diameter and 11.27 cm (4.4375 in) in length was chosen. One lead of the thermocouple was threaded through the annulus and the other was glued with a fast drying modelers' glue along the outer surface, allowing the microthermocouple junction to protrude slightly from the tip of the annulus. The leads at the opposite end of the annulus were welded to .0762 mm (.003 in) diameter wire which subsequently was connected to 28 AWG extension wire to the computer. The annulus was mounted as shown in Figure 13. Henceforth, this device will be referred to as the probe.

## E. PROBE ACTUATOR ASSEMBLY

The cross sectional area of the probe as seen by the jet was further reduced by orienting the probe tangentially to the trajectory of the jet as shown in Figure 14. This photograph indicated that the probe created no noticeable interference with the jet hydrodynamics. Probe orientation was accomplished by the linkage assembly shown in Figure 15. The fixed end of the probe was hinged to a streamlined tube 23.495 cm (9.25 in) long with a maximum width and depth, as seen by the jet, of 3.175 mm (.125 in) and 6.35 mm (.25 in) respectively. It was rigidly connected to the mounting

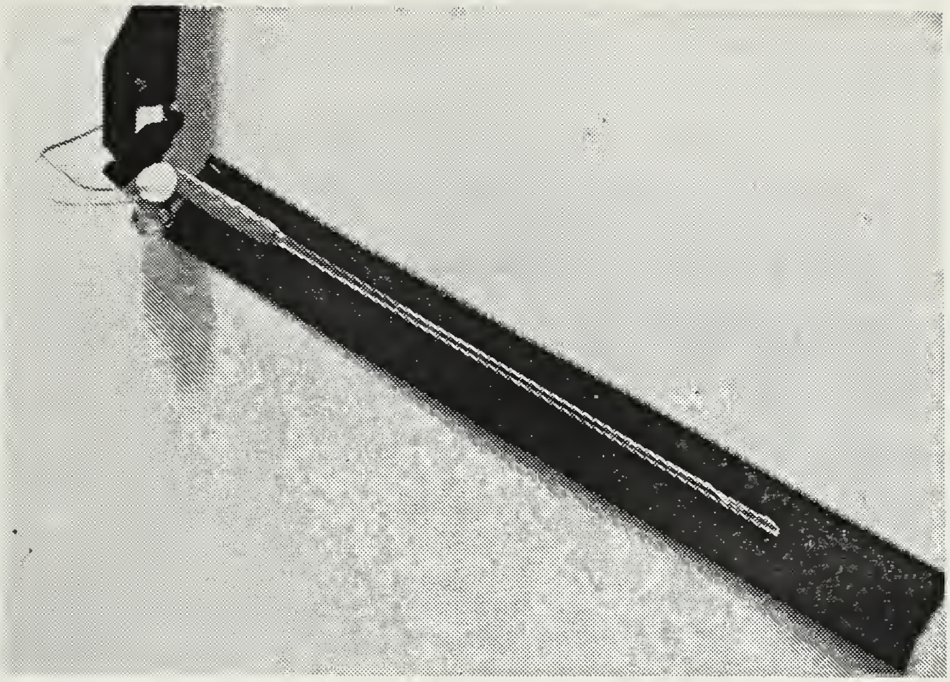


Figure 13. Probe Profile


Figure 14. Probe in Jet

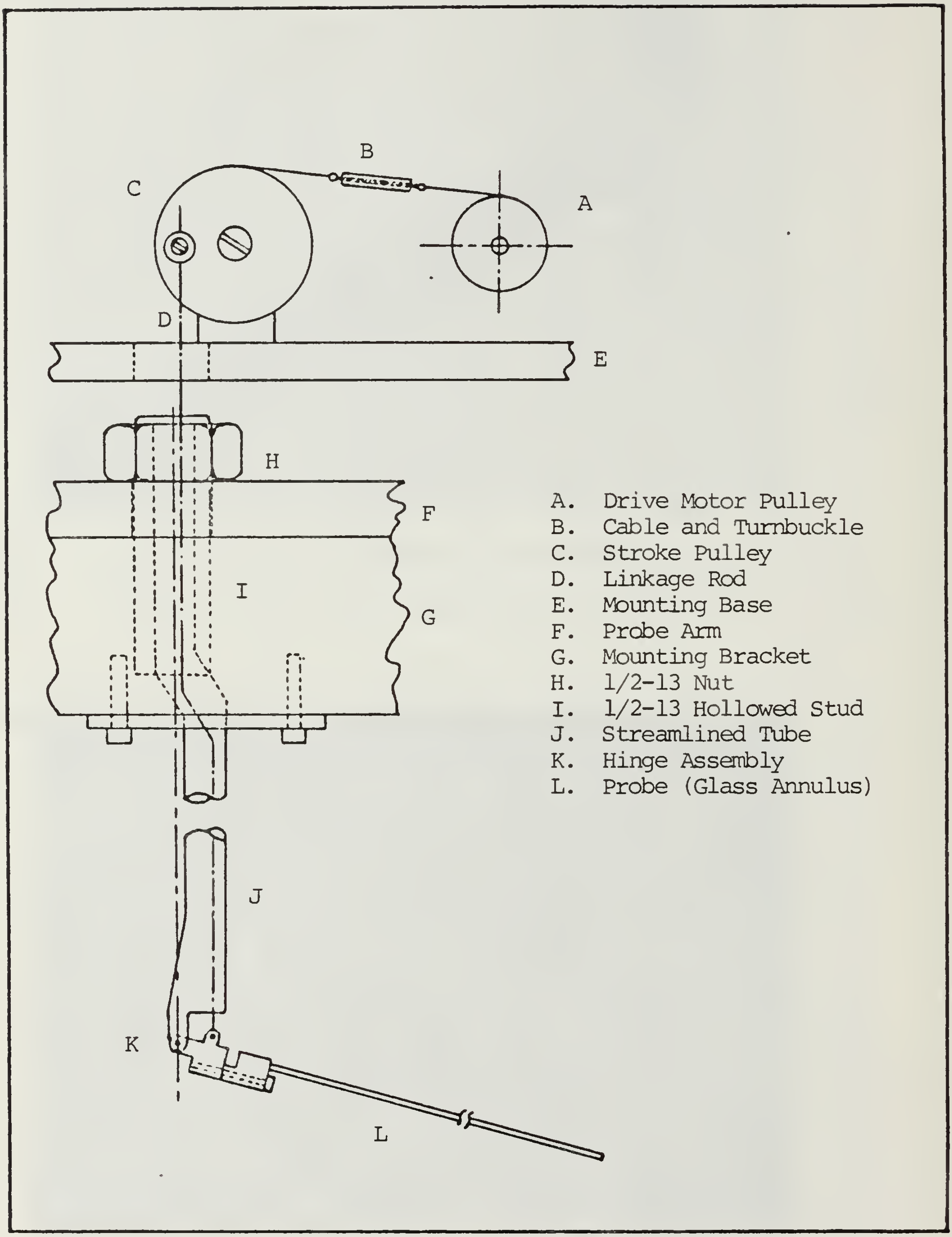
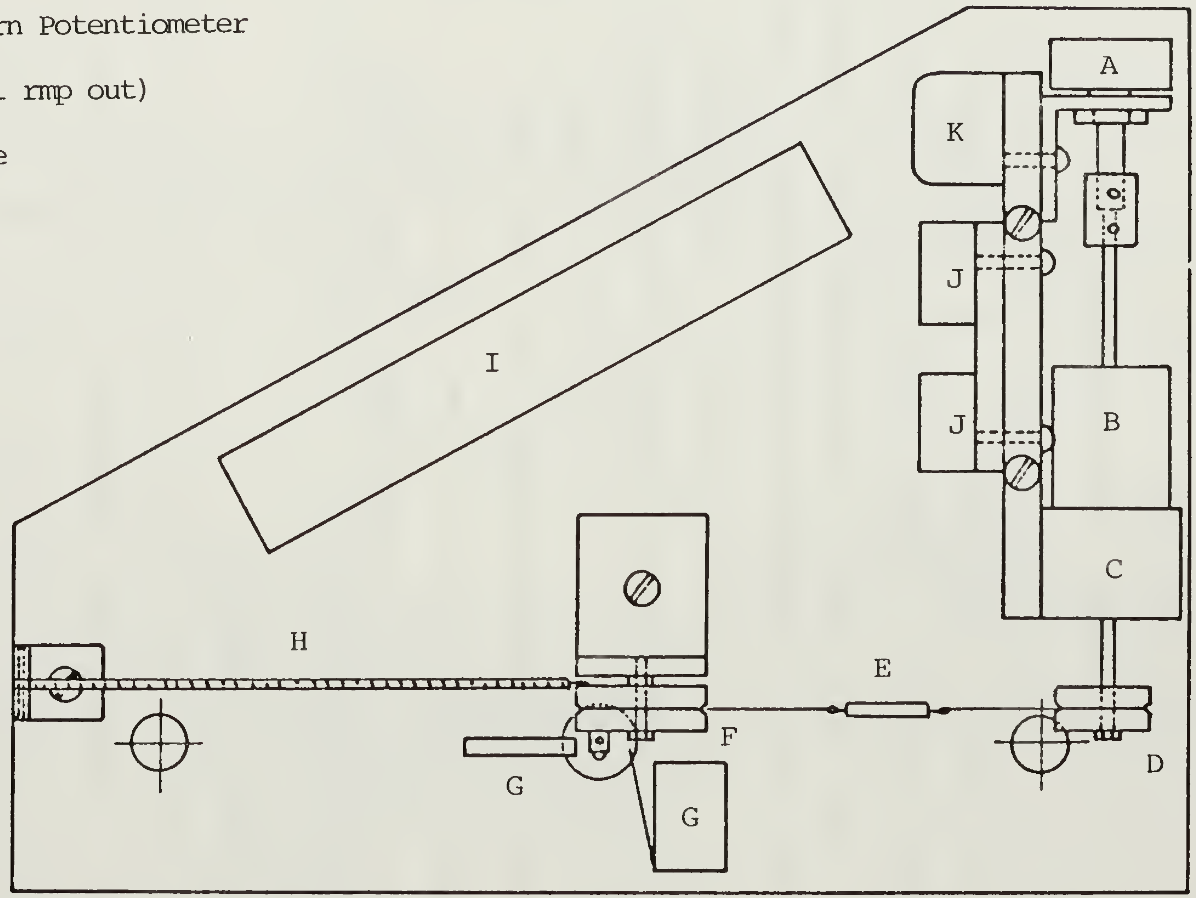



Figure 15. Probe Assembly Linkage

bracket as shown in Figure 15 which was connected to the probe arm shown in Figure 3 by a single stud which allowed pivoting of the probe from side-to-side. The stud was also hollowed so that a linkage rod could extend from the hinge assembly through the tube and stud to a stroking pulley which was rotated by a small motor. The hinge assembly and the stroking pulley were spring loaded to reduce hysteresis. As shown in Figures 16 and 17, the 1.5 VDC motor, geared to one rpm, was directly coupled to a potentiometer as well as the drive pulley. The potentiometer was configured in a voltage divider such that the amount of motor rotation, and ultimately the degree of probe deflection, was proportional to the potential difference sensed across the potentiometer. Limit switches were installed at the stroke pulley as shown in Figures 16 and 18 to prevent damage to the linkage assembly due to over-rotation.

## F. MICROCOMPUTER INTERFACE

The data collection process consisted of adjusting the probe angle of deflection, traversing the three-dimensional positioning platform and measuring temperature profiles. All of the mechanisms which controlled these events were interfaced to an HP-9826 computer shown in Figure 19 through an HP-6942A multiprogrammer which performed high speed analog-to-digital conversions and ultimately provided control signals to govern relays within the system. Refer to MAIN_T in Appendix B for the microcomputer software which directed this process.




A. 10 kΩ Linear One-turn Potentiometer
B. 1.5 VDC Drive Motor
C. Reduction Gearing (1 rmp out)
D. Drive Motor Pulley
E. Turnbuckle and Cable
F. Stroke Pulley
G. Limit Switches
H. Loading Spring
I. 10 Terminal Buss
J. Type MRR1CDL Relays
K. 2 Terminal Buss

Figure 16. Probe Actuator Assembly

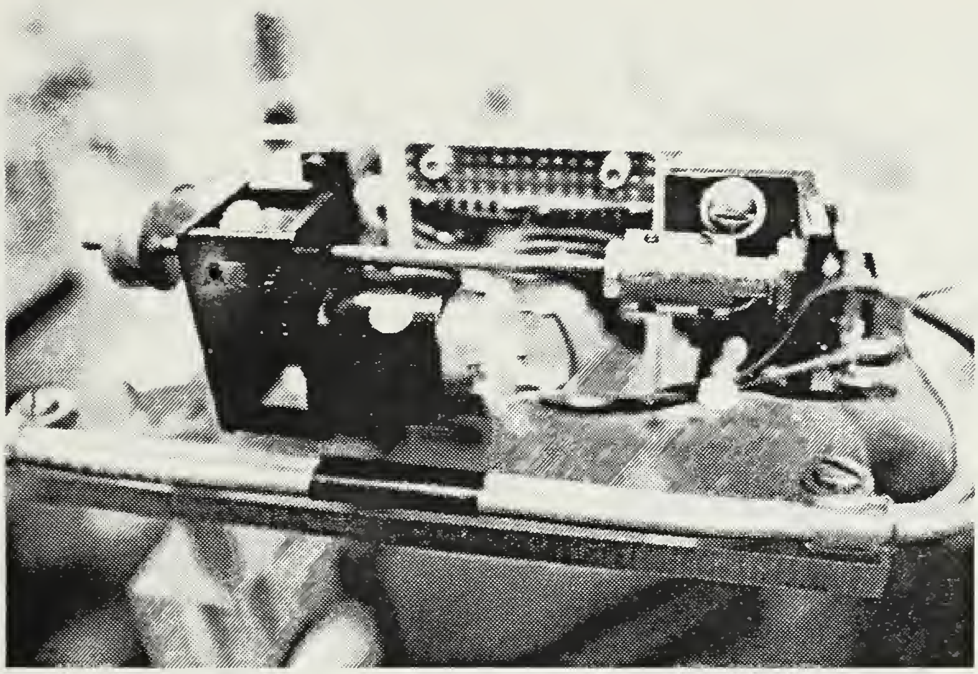


Figure 17. Probe Actuator Motor-Potentiometer Arrangement

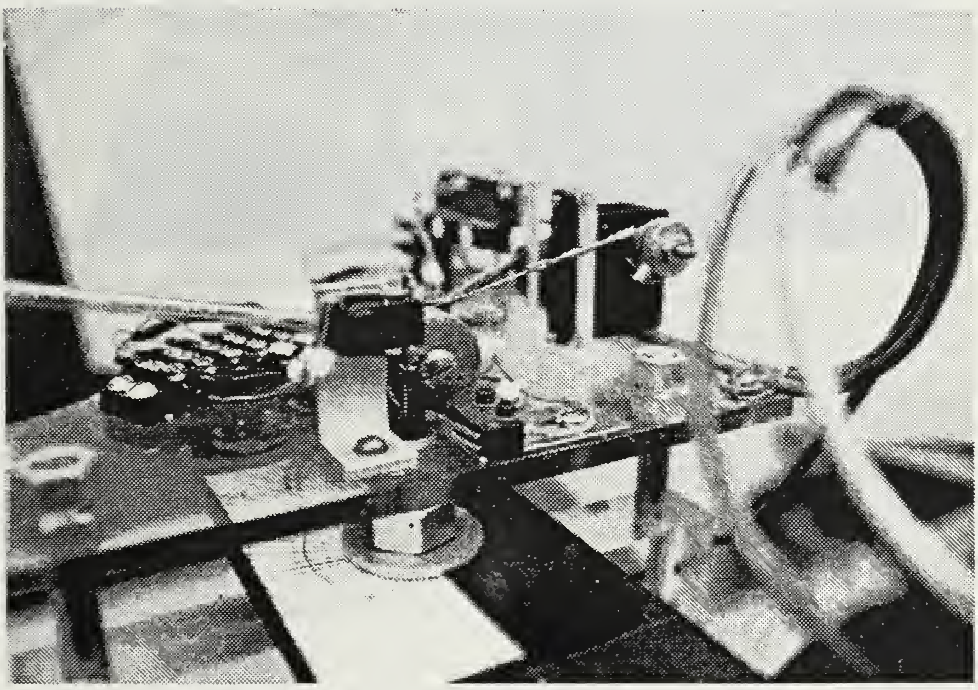


Figure 18. Probe Actuator

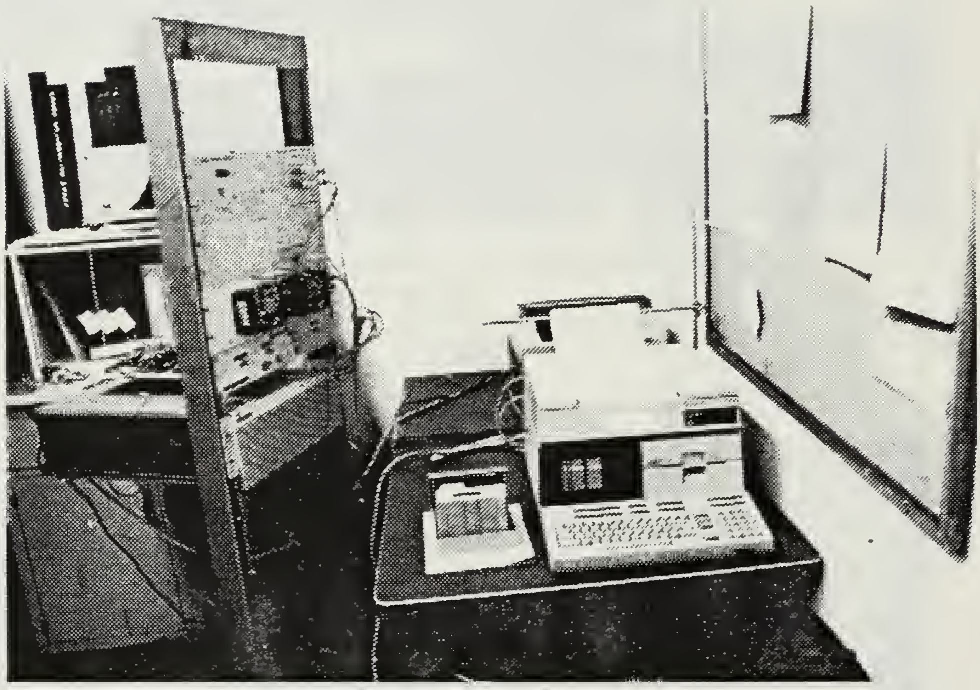


Figure 19. HP-9826 Microcomputer

1. Probe Angle Adjustment

As discussed in Section III.E, a potentiometer configured as a voltage divider provided probe angle feedback to the computer as shown in Figure 20. The direction of motor rotation was controlled by the computer through Type-MRR1CDL replays connected as shown in Figure 21. When the probe was at a desired position, a 5.0 VDC signal was applied to pins 6L and 6R which allowed both relays to assume the normally closed (NC) positions which opened the power circuit to the motor. When it was desired to rotate the motor clockwise, pin 6R was grounded which resulted in 5.0 VDC applied across the coil in the right-hand relay. This caused the relay to assume its normally open (NO) position resulting in a 1.5 VDC signal at terminal B of the motor causing it to rotate in the clockwise direction. The left-hand relay was activated in a similar manner for counterclockwise rotation. Refer to PROBE_SUBS in Appendix B for probe positioning software.

2. 3-D Positioning Platform Movement

Positioning platform movement was controlled in a manner similar to the probe and was discussed in detail by Nickodem [Ref. 2]. Refer to MTR_SUBS in Appendix B for associated HP-9826 software.

3. Temperature Data Collection

Three thermocouples were monitored in the data collection process. A Type-T thermocouple located in the inlet chamber measured the ambient fluid temperature in the flume,

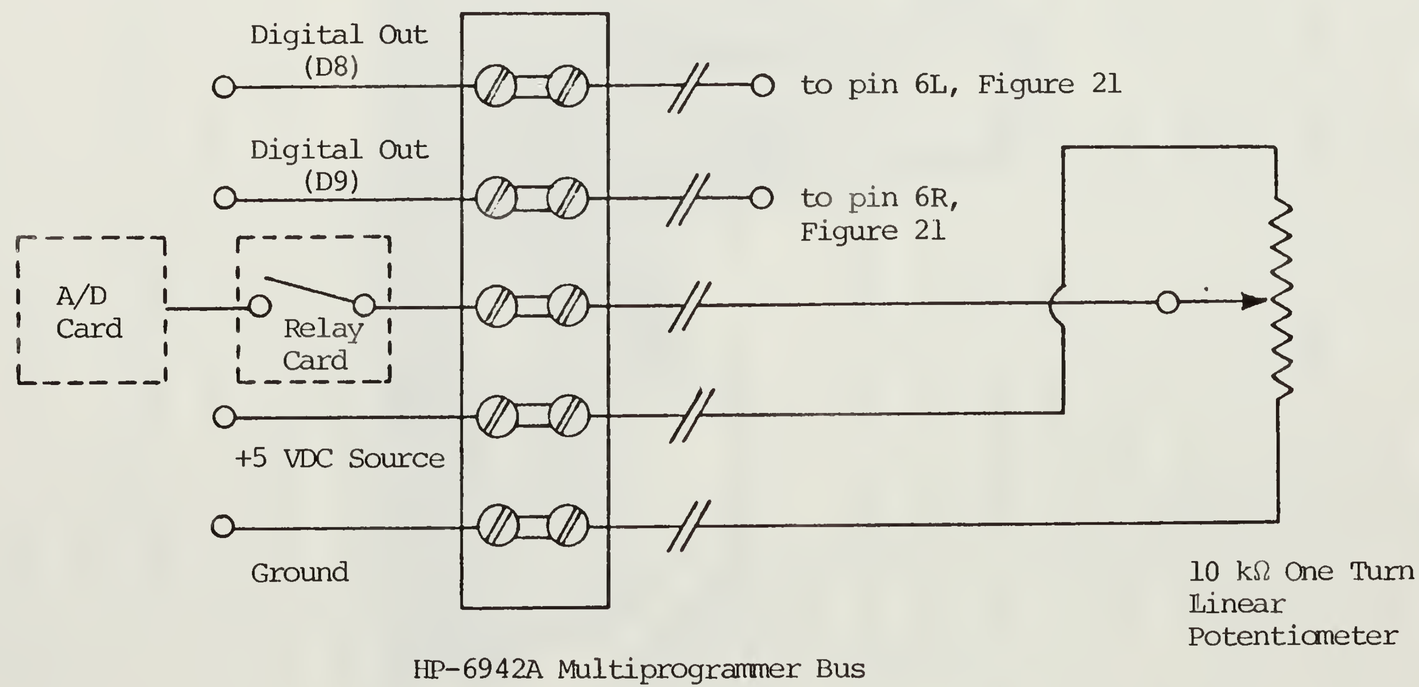



Figure 20. Computer Bus and Probe Voltage Divider Wiring Diagram

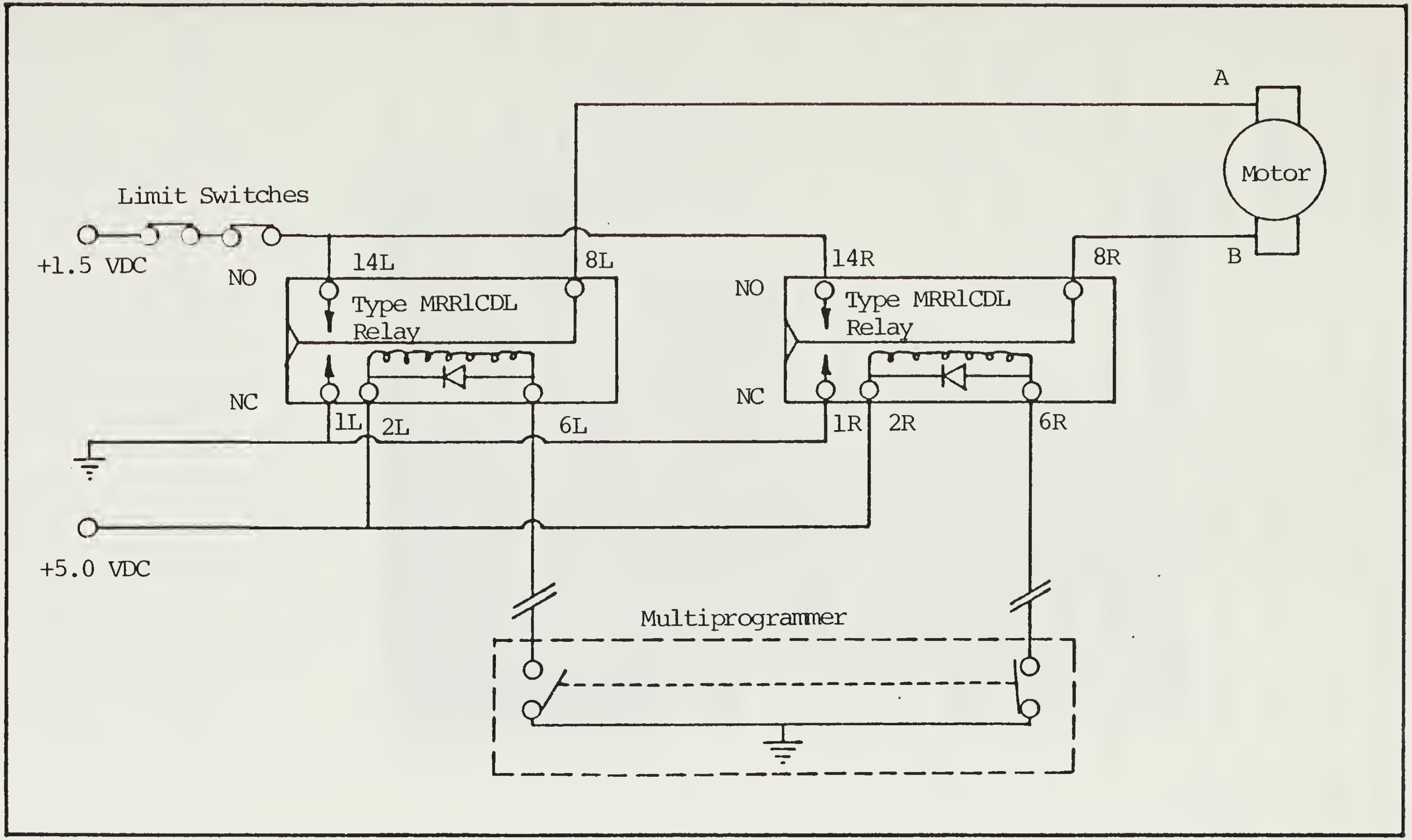



Figure 21. Probe Motor Wiring Diagram

a Type-T thermcouple located in the tubing between the heater and the nozzle measured nozzle temperature and a Type-E microthermocouple in the probe measured the temperature in the jet. The EMF's generated by these thermocouples were amplified by "Omega Omni-Amp IIB" millivolt amplifiers shown in Figure 22 prior to entering the multiprogrammer for analog-to-digital conversion and eventual transformation to temperature readings. Fourth-order least squares coefficients for this conversion were taken from Beckwith [Ref. 5]. Operation of the crossflow circulation pump created sufficient electrical interference to distort the thermocouple signals. This problem was corrected by applying a thin coating of silicon sealant to the Type-T thermocouple junctions and by connecting the crossflow circulation pump casing, the nozzle and the jet tubing in the vicinity of the nozzle thermocouple to a common ground. Because the jet tubing was plastic, it was necessary to manufacture a brass "T" connector as shown in Figure 23 which was grounded and located in close proximity to the thermocouple junction. Refer to T_SUBS in Appendix B for associated software.

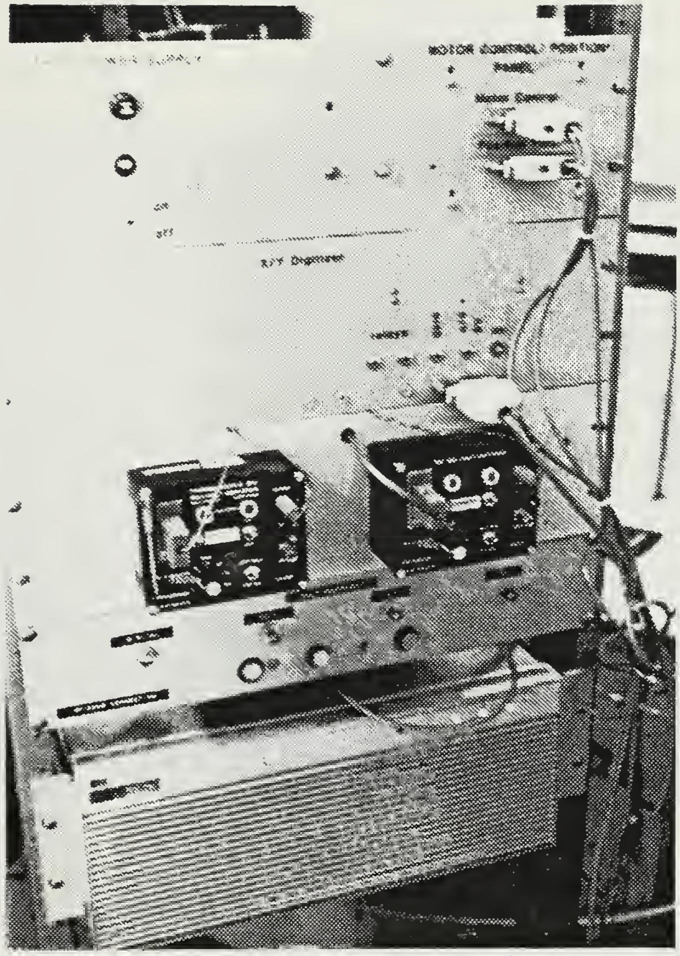


Figure 22. Thermocouple Amplifiers and HP-6942A Multiprogrammer

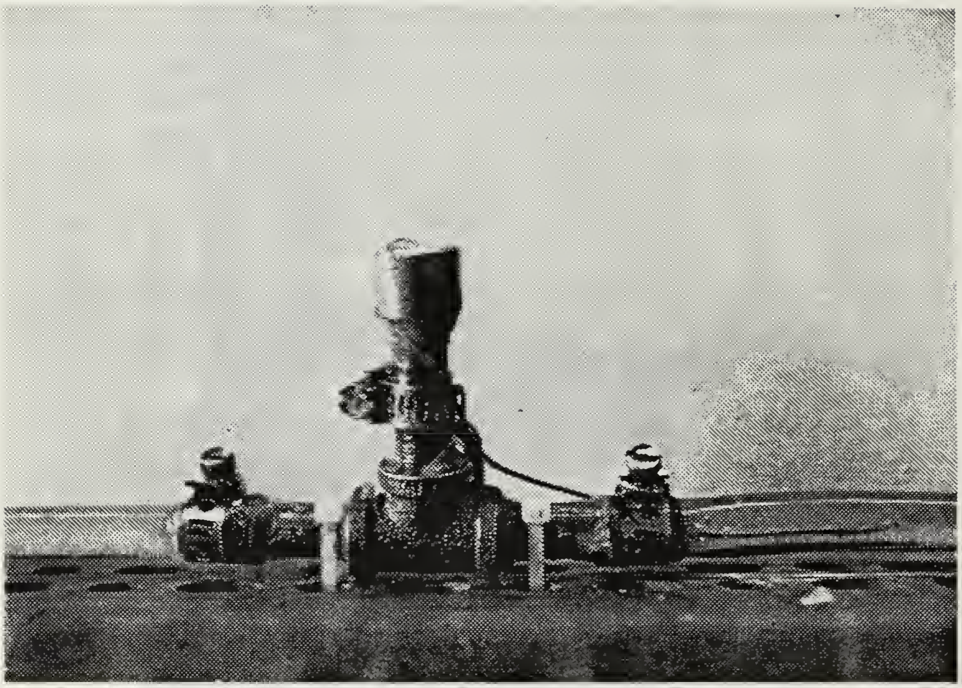


Figure 23. Nozzle Thermocouple Grounding Arrangement

## IV. EXPERIMENTAL PROCEDURES

### A. CALIBRATION

Before the data collection process could begin, the rotometer, the thermocouples, the probe and the positioning platform had to be calibrated. The detailed steps taken are discussed below.

#### 1. Rotometer

With a constant level maintained in the head tank and the jet tubing disconnected from the nozzle and elevated to the same height as the top of the nozzle, five 100 ml samples were drawn through the rotometer and timed to the nearest 0.01 second at each rotometer reading from 10% to 75% in 5% increments. Flowrates and standard deviations in ml/s are shown in Table 1.

#### 2. Thermocouples

Since nozzle and probe temperatures were to be normalized by the ambient temperature, the nozzle and probe thermocouples were calibrated relative to the ambient thermocouple by using the microcomputer program T_CAL in Appendix B. The procedure followed is outlined in the initial comments of the program. Coefficients for first order curve fits were solved by the least squares method with the mainframe programs TCAL and TFIT found in Appendix C.

3. Probe

As the probe assembly was being developed, it was convenient to test its suitability with the probe calibration panel shown in Figure 24. Resistance changes across the potentiometer were recorded for varying degrees of deflection. Analysis of this information led to improved designs from the standpoint of reduced hysteresis and repeatability. The microcomputer program PROBE_CAL in Appendix B was developed to enable calibration of the final design after it was installed in the system as shown in Figures 25 and 26. The calibration procedure is outlined in the preliminary comments of the program.

4. 3-D Positioning Platform

The positioning platform was calibrated in a manner that placed the tip of the probe at desired locations within the flume relative to the tip of the nozzle. Referring to the coordinate system illustrated in Figure 2, the center of the nozzle was defined as (0,0,0) in xyz-coordinates. The following relationships apply to the probe geometry shown in Figure 27:

$$X(\text{real}) = X_o - R_a \cos\alpha \tan(\pi/4 - \alpha/2)$$

$$Y(\text{real}) = Y_o + r_p(1 - \cos\gamma) + R_a \cos\alpha$$

$$Z(\text{real}) = Z_o - r_p \sin\gamma$$


Figure 24. Probe Design Test Panel

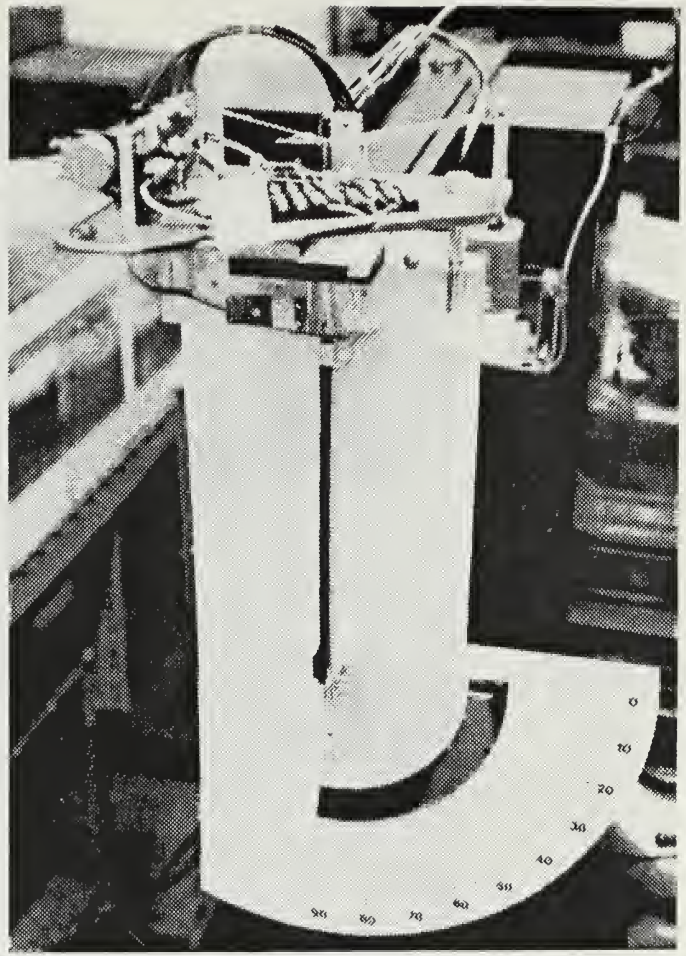


Figure 25. Probe Calibration Panel

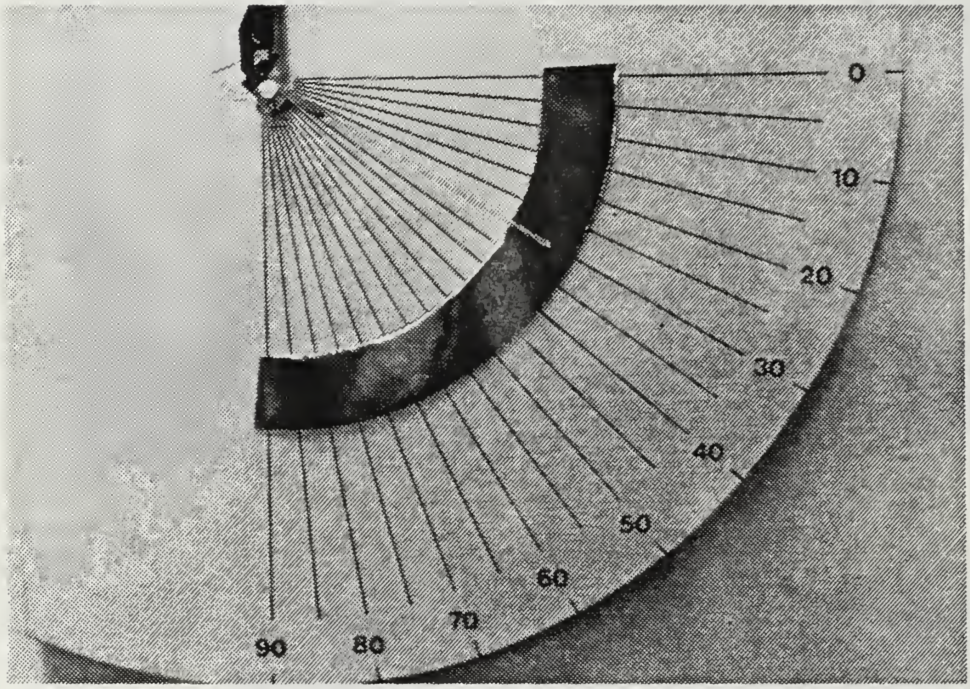



Figure 26. Probe Calibration Panel

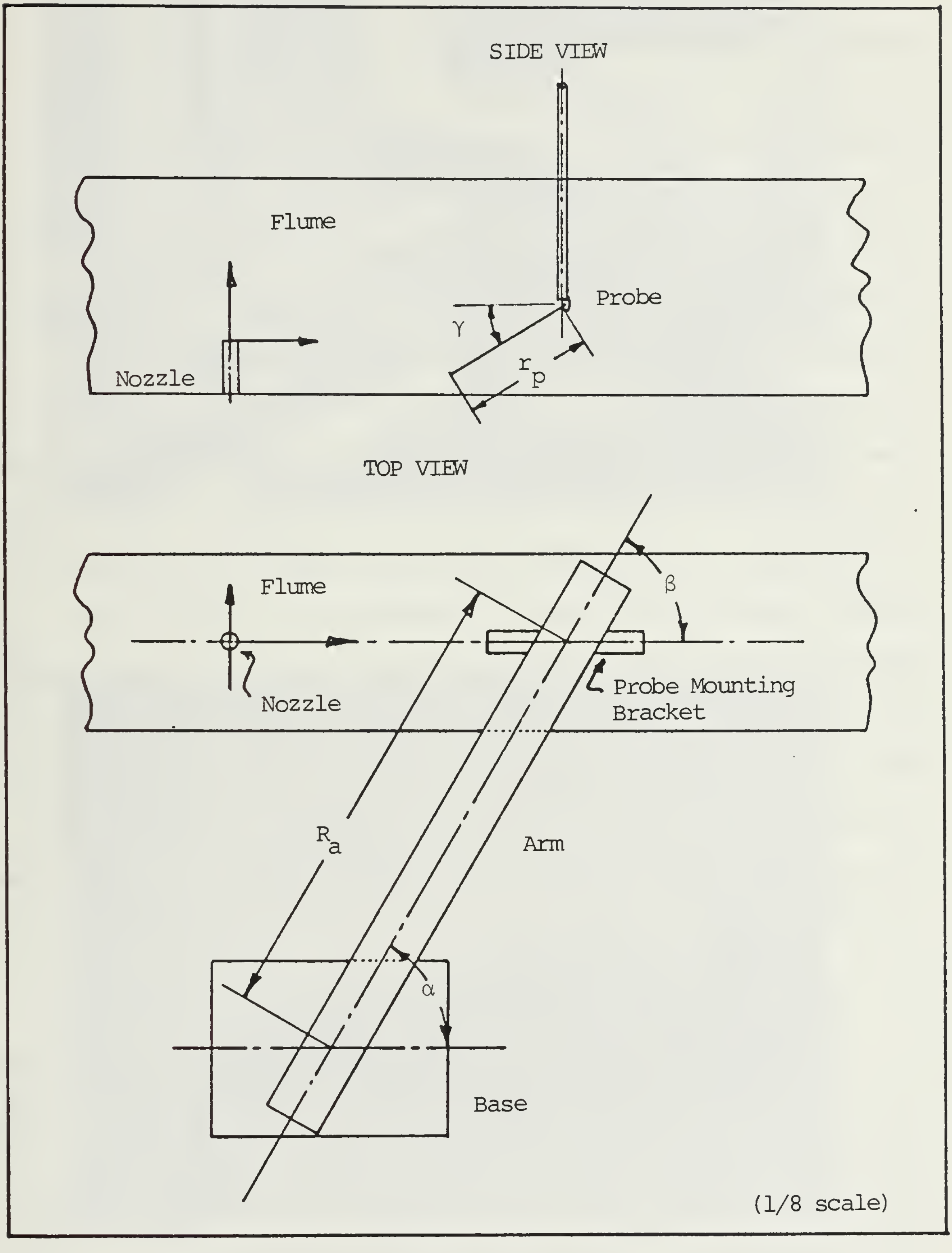



Figure 27. Probe Positioning Geometry

$(X_o, Y_o, Z_o)$ was the position of the milling machine bed when the tip of the probe was at position (0,0,0) with $\gamma = 0$ and $\alpha = \beta = 90$ degrees. For calibration, the probe and probe arm were configured with these settings as shown in Figure 28. With measured values of $r_p$ and $R_a$ entered into the microcomputer program MAIN_T, the calibration was accomplished by the program MOTOR_CAL. The step-by-step procedure followed was outlined in the subprogram "SUB Calibrate." As illustrated in Figures 3, 27 and 28, the length of $R_a$ could be modified to compensate for adjustments of $\alpha$ and $\beta$ to positions other than 90 degrees. Decreasing $\alpha$ increased the distance along the Y-axis in which the probe could be positioned. Increments of $\alpha$ and $\beta$ were scribed on the top of the base and at the tip of the probe arm in Figure 28 to accommodate this change, if desired. The program MAIN_T queried the user for the value of $\alpha$ and assumed $\alpha = \beta$. The calibration software also established position limits to prevent driving the probe into the sides of the flume.

## B. PRELIMINARIES

Crossflow velocity was determined by injecting blue food coloring into the flow and timing its travel through a 1.0 m interval. The average of several trials indicated the velocity was .130 m/s (.427 ft/sec) with the flume outlet valve closed two turns from its fully open position.

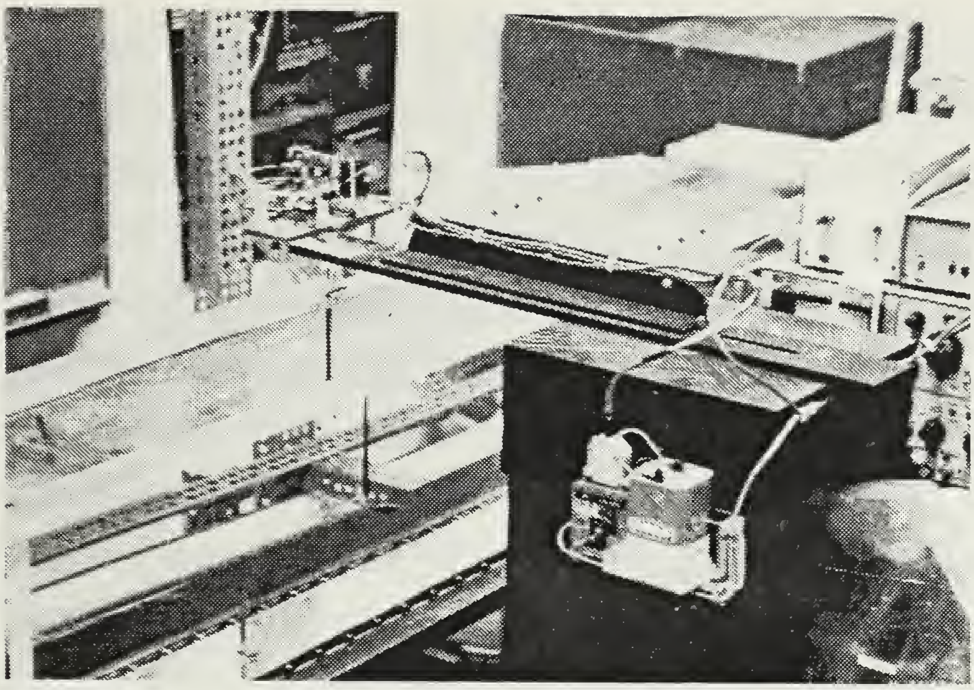


Figure 28. Probe Arm Positioning for Motor Calibration

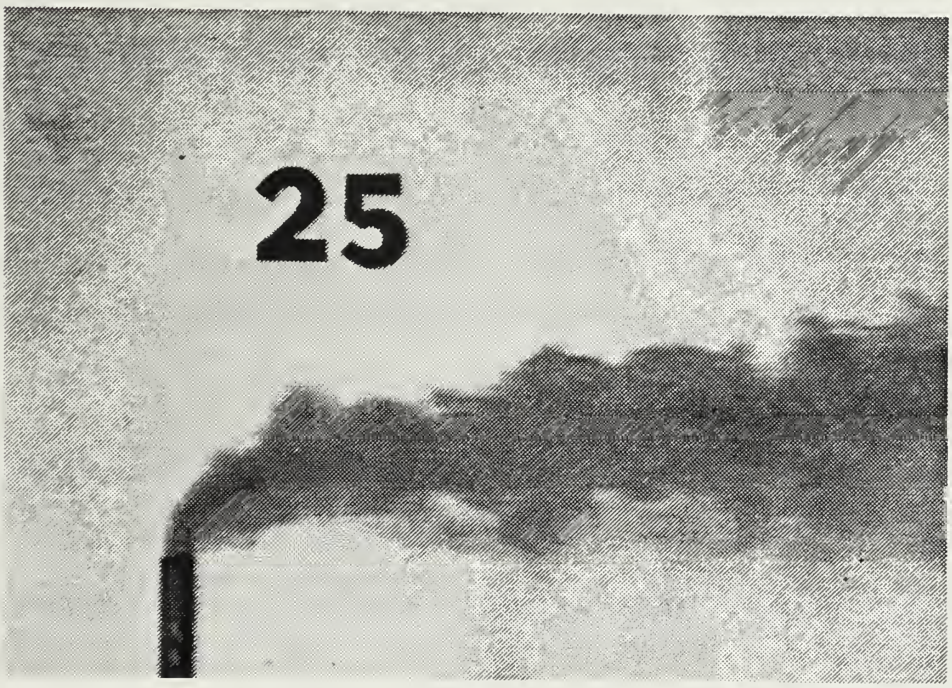



Figure 29. Typical Buoyant Jet as Obsered with Dye Injected

Photographs of jet profiles as shown in Figure 29 were taken to determine jet trajectory and halfwidths along the streamwise axis. This was done by injecting blue food coloring into the jet flow as discussed in Section III.C. The specific gravity of the food coloring was found to be considerably less than that of water. To eliminate the added buoyant effect this would have had on the jet, a small quantity of alcohol was mixed with the food coloring as suggested by Merzkirch [Ref. 6]. The amount of alcohol added was determined by trial and error. As small quantities were added and mixed, samples were gently placed on the surface of a beaker of water. Pure food coloring laid on the surface and very slowly mixed with the water. As alcohol was added, this buoyant effect grew progressively less and the mixture would settle into the water. The mixture was considered satisfactory when it no longer laid on the surface, but settled to some equilibrium position in the beaker.

Slide photographs of the jets were projected onto large sheets of 3.175 mm (.125 in) grid graph paper and digitized along approximate streamwise axes and half-width trajectories. A scaling factor was determined by equating the projected width of the nozzle to its known outer diameter of 7.9375 mm (.3125 in). The above data was fit to the Michaelis-Menter Equation [Ref. 7] shown below by the least squares method with the mainframe program JETCURV in Appendix C:

$$Z = \frac{ay}{b + y}$$

Correlation coefficients close to 1 were consistently obtained. To determine positions within the jet at which to make temperature measurements, five evenly spaced positions per jet flow rate were selected along the streamwise axis in the zone of established flow. Data planes slightly larger than the jet width were centered at these points and oriented perpendicular to the streamwise axis. One hundred data points were selected in a symmetric square matrix with points most densely populated near the center. The planes were identified alphabetically and in consecutive order from "A" to "F", where "A" represented the plane nearest the nozzle. The positions were entered into the microcomputer and stored by plane on a floppy disk by the program LOAD_XYZ in Appendix B. Accompanying each data point was a probe deflection angle used to orient the probe parallel to the path of the jet to minimize interference. This angle was determined by evaluating the first derivatives of the equations developed for the streamwise axis and the half-widths and performing an interpolation based upon the data points' position relative to the two curves.

## C. DATA ACQUISITION

The flow systems were placed into operation and the ambient and nozzle temperatures were monitored with the program T_SUBS to evaluate system stability and readiness for data acquisition. The system usually took approximately two hours to come into equilibrium. This could be monitored by watching the jet nozzle temperature. When conditions were stable, data consisting of two hundred probe, ten ambient and ten nozzle temperature samples per position was collected, one plane at a time, by the program MAIN_T. The following information was stored on a floppy disk for each data point: x, y, and z coordinates; mean probe, nozzle and ambient temperatures and the standard deviation of the probe measurements. The data was transferred to the mainframe computer by using a modem, the microcomputer program SEND_DATA and the mainframe program GRAB.

## D. DATA REDUCTION

The raw data was organized into a more usable format by the mainframe program TDATA which also converted the XYZ coordinates into the XSW system shown in Figure 2. The resulting data was selectively sent to the program CONTOUR4 which applied calibration coefficients to the temperature data and normalized it in the following manner:

$$T = \frac{T_p - T_a}{T_n - T_a}$$

where $T_p$ was the jet temperature as measured by the probe, $T_a$ was the ambient fluid temperature and $T_n$ was the temperature of the jet within the nozzle.

Contour plots of this information, generated by the CONTOUR option of the graphics package DISSPLA [Ref. 8], are presented in Figures 30 through 35.

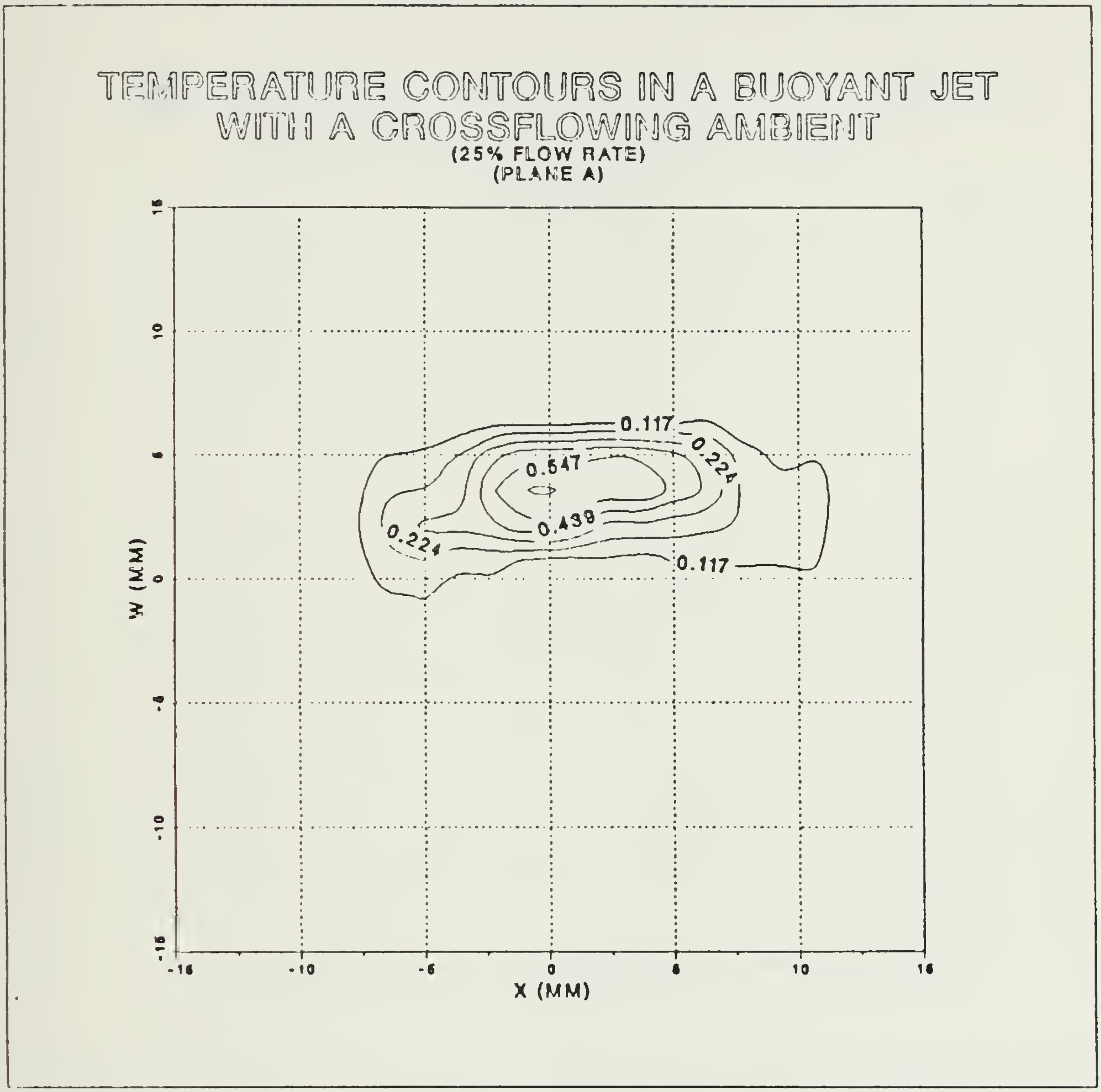



Figure 30. Plane A Temperature Contour Plot (large scale)

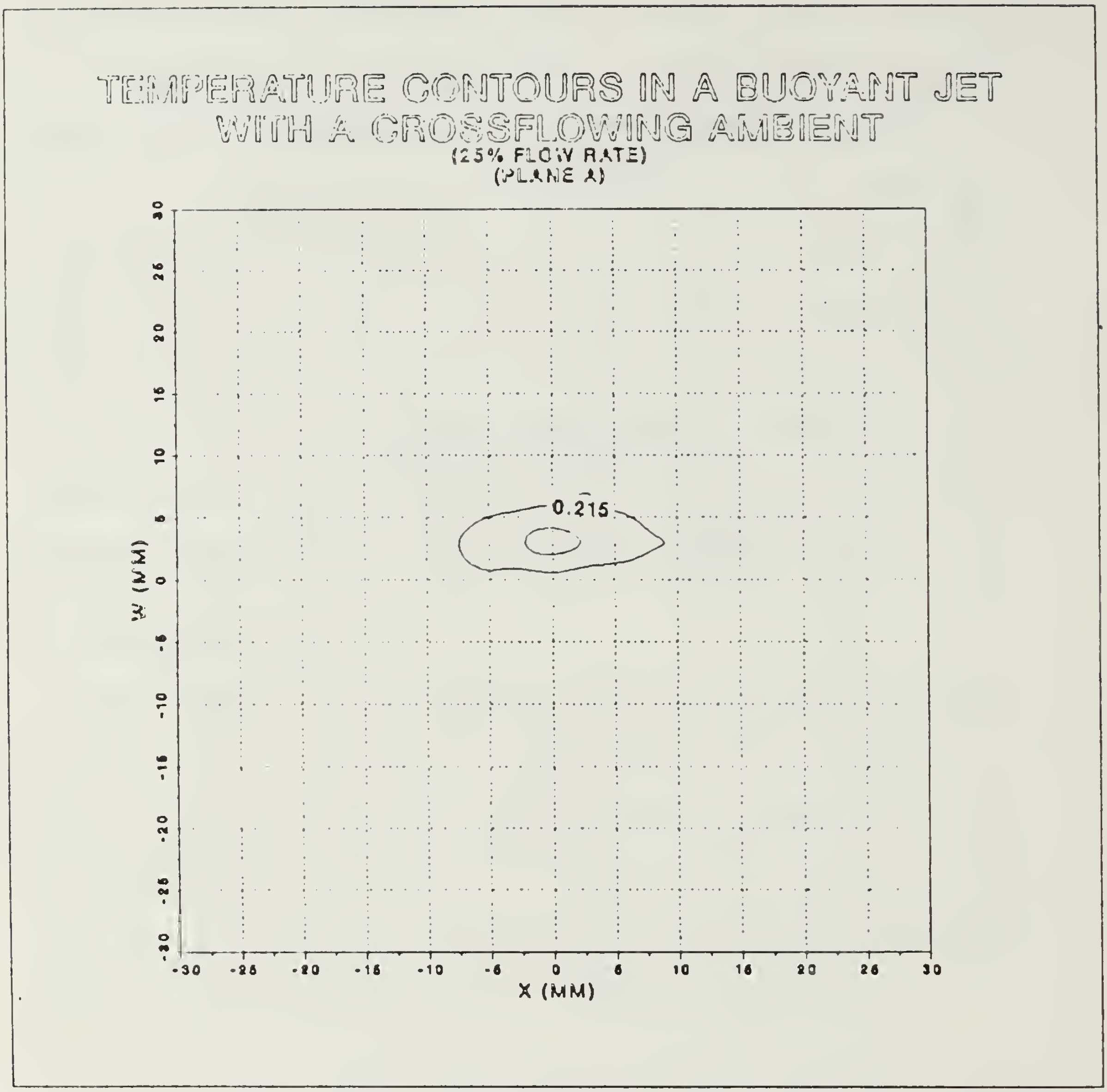



Figure 31. Plane A Temperature Contour Plot (small scale)

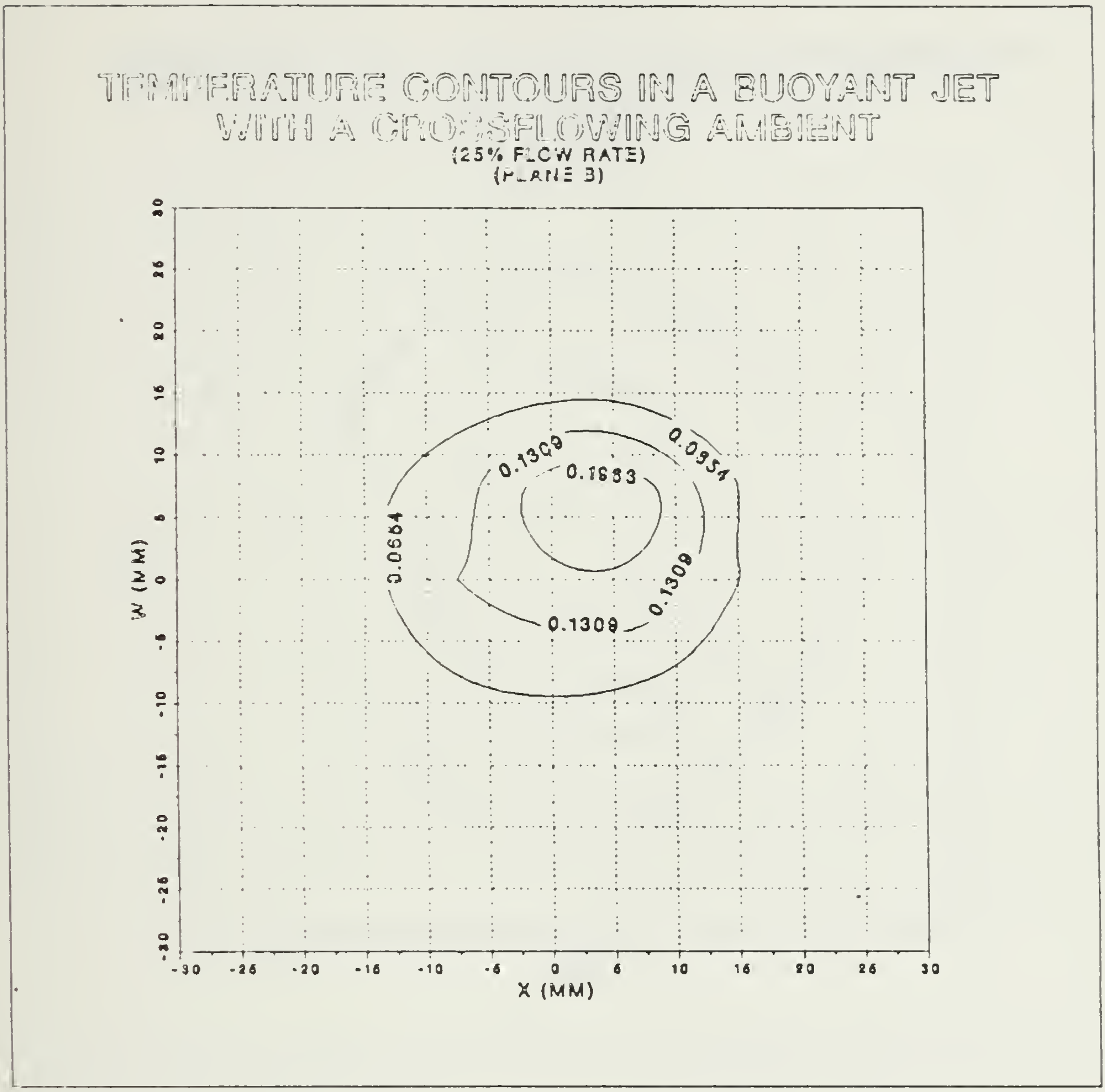



Figure 32. Plane B Temperature Contour Plot

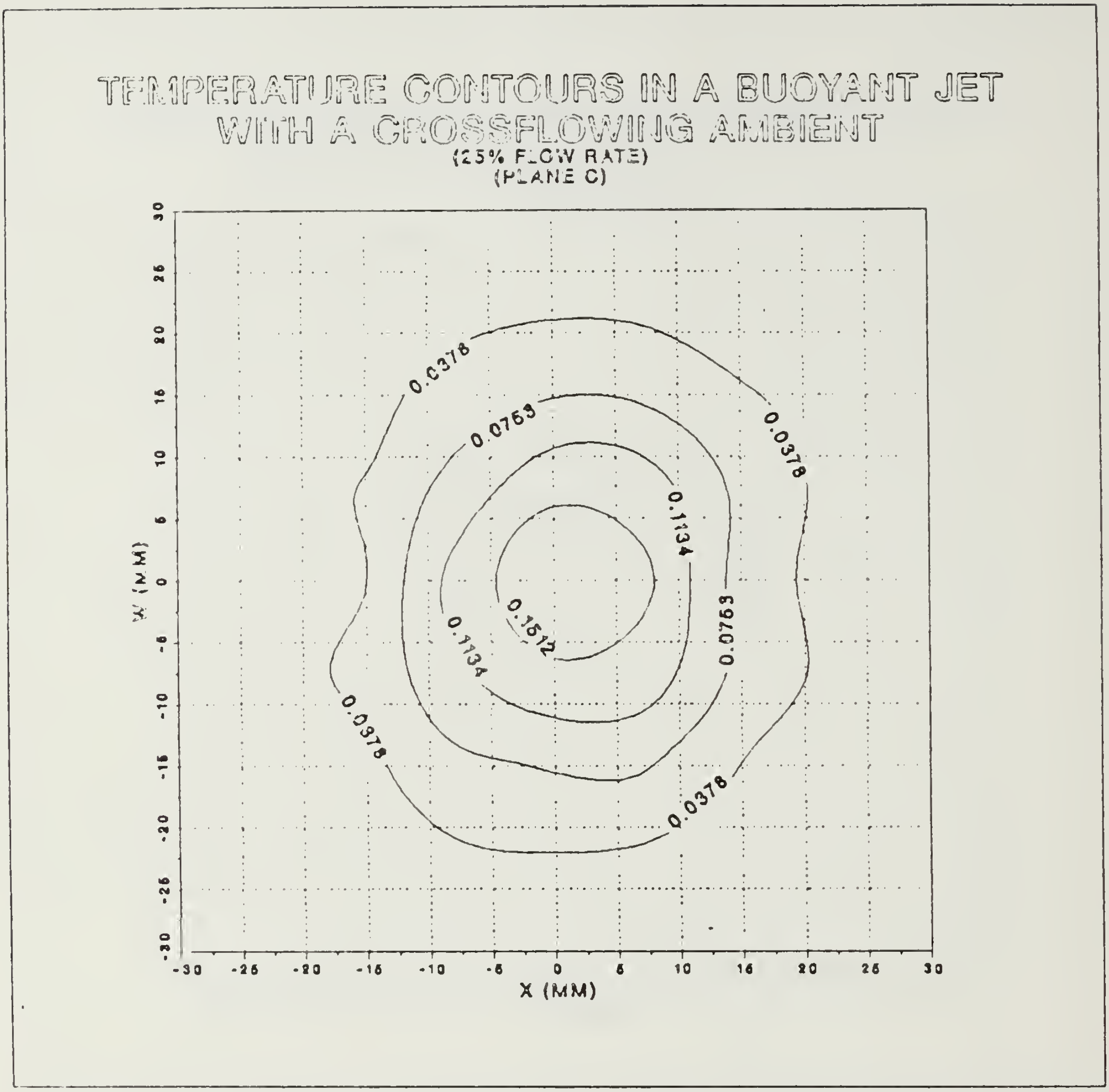



Figure 33. Plane C Temperature Contour Plot

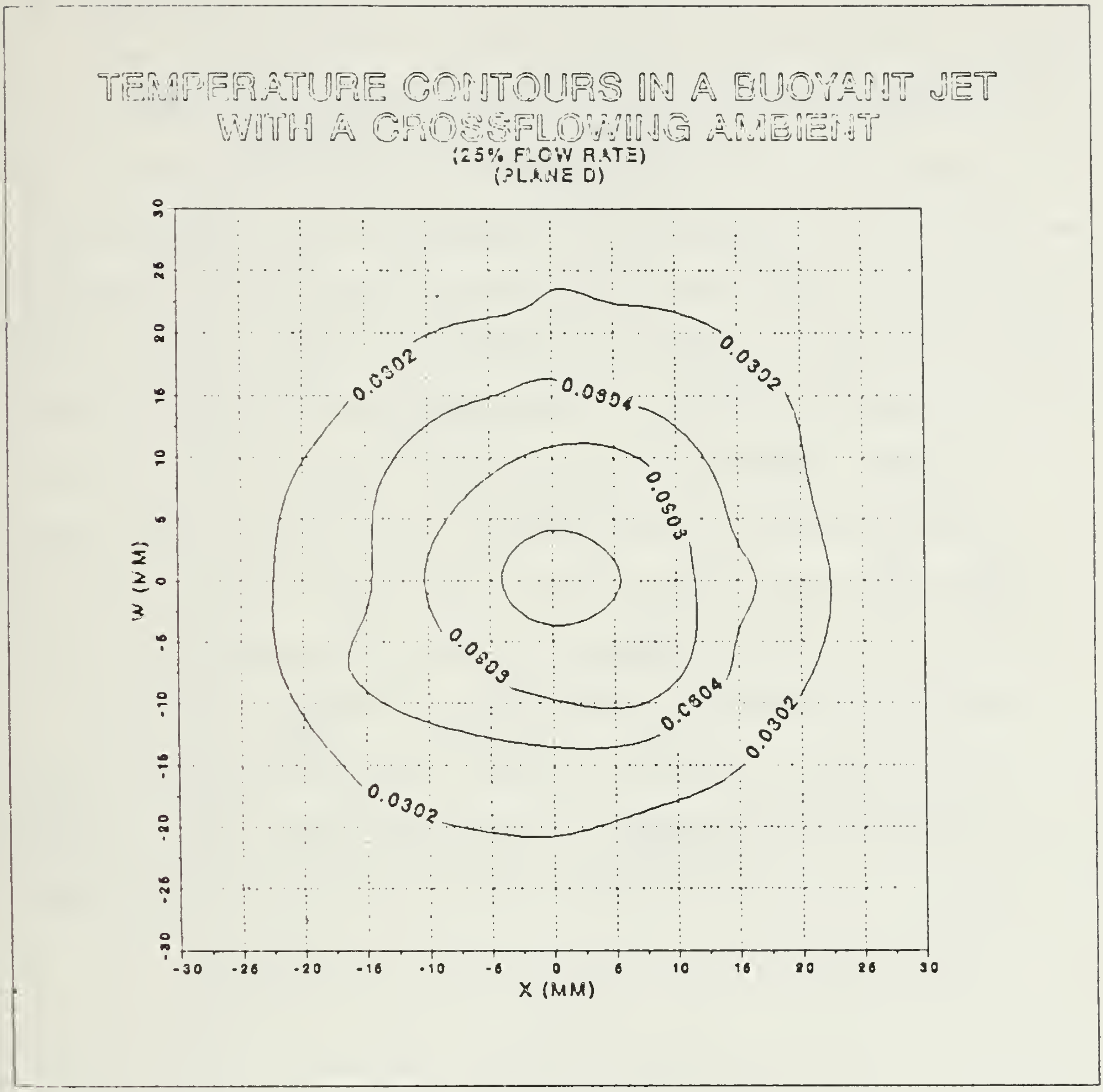



Figure 34. Plane D Temperature Contour Plot

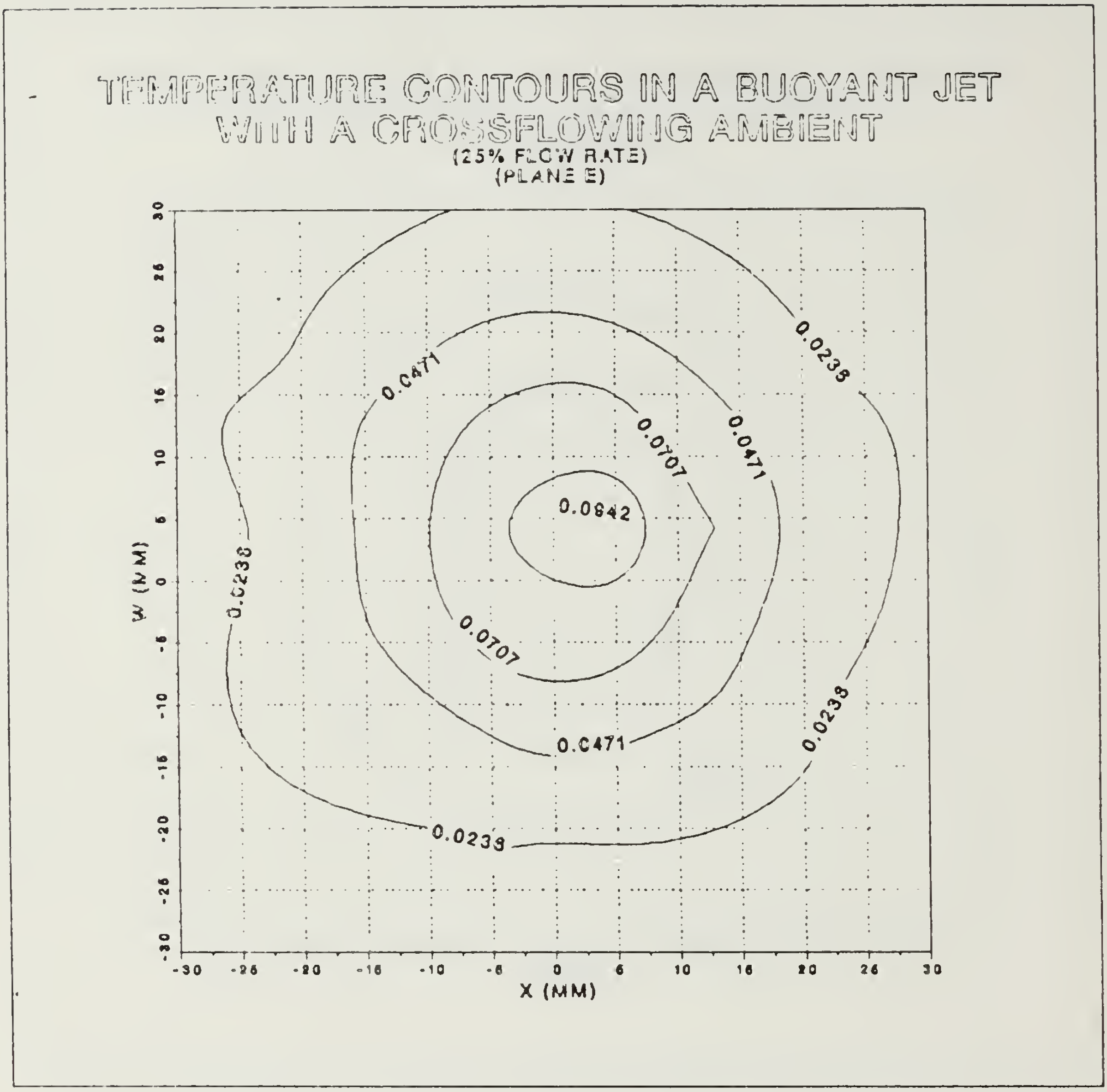



Figure 35. Plane E Temperature Contour Plot

## E. RESULTS

The contour plots found in Figures 30 through 35 support the conjectures in Section II.C concerning the effects of the crossflow. Figure 30, a plot of plane A centered on the streamwise axis 46 degrees from horizontal and 7.327 mm (.288 in) downstream of the nozzle shows significant distortion. Figures 31 through 35 show planes A through E sequentially plotted on the same scale in order to observe overall jet behavior. Plane E was located 87.313 mm (3.438 in) downstream of the nozzle and 86 degrees from horizontal. It can be seen that as the jet traveled further downstream, the distorting effect grew progressively less, as expected.

The rate of heat transfer from the jet to the ambient was calculated for each plane utilizing the temperature distribution matrix generated in the program CONTOUR4 in Appendix C and the following relationship:

$$\dot{Q} = \sum_{i=1}^{m} \sum_{j=1}^{n} \rho \, c_p \, A_{ij} \, U_{ij} \, T_{ij}$$

where $\rho$ was the relative density of the jet, $A_{ij}$ was the area of each matrix segment, $U_{ij}$ was the velocity in each segment, $c_p$ was the specific heat of the jet and $T_{ij}$ was the temperature in each segment. Velocity was measured along the streamwise axis by a laser Doppler velocimeter (LDV). It appeared to be nearly constant in the region of the jet observed. The mean and standard deviation was 44.875 mm/s and 1.8 mm/s respectively. By assuming the Gaussian profile shown in Section II.B, velocity was determined at radii corresponding to each segment in the matrix mentioned above. The rates of heat transfer are shown in Table 2.

## V. CONCLUSIONS AND RECOMMENDATIONS

The objective of this thesis was to develop a computer-aided data acquisition system and construct a microthermocouple probe to be used by follow-on students to study temperature distributions in turbulent buoyant jets. Sample data was taken to verify system operability. Based on results, the system performed in a satisfactory manner and will be an invaluable tool for subsequent studies of buoyant jets in a crossflowing ambient.

Data point positions were hand calculated and loaded into the microcomputer with the program LOAD_XYZ. This was an extremely time consuming task and distracted the user from defining more than 100 data points per plane. The system can be greatly improved with the addition of microcomputer software that would automatically determine and load data point positions. Data point population could then be increased with ease which should result in smoother contour plots and more accurate heat transfer calculations.

It was necessary to continuously add fresh water to the crossflow system as an equal amount was drained from it in order to maintain the crossflowing ambient at a constant temperature. This was because the cooling coil located within the flow settling chamber was inadequate to compensate for the heat added to the system by the jet and the crossflow circulation pump by itself. Although it was possible to maintain the ambient constant within 1.4 C by this method, in the interest of conserving water, it is recommended that either a larger capacity chilled water bath or a cooling system that circulates a refrigerant rather than water be appropriated for this purpose.

## APPENDIX A

## UNCERTAINTY ANALYSIS

Experimental uncertainty was analyzed in accordance with the guidelines set forth by Holman [Ref. 9]. Uncertainties in the primary measurements, based upon manufacturer specifications and/or the number of significant digits which could be read, follow:

| | | |
|---|---|---|
| 1. | Time (rotometer calibration): | .01 s |
| 2. | Volume (rotometer calibration): | 1.0 ml |
| 3. | Rotometer reading: | 1.0 percent |
| 4. | 3-D positioning platform resolution: | .1524 mm |
| 5. | Probe deflection angle resolution: | .5 degrees |
| 6. | Thermocouple resolution: | .0099 °C |
| 7. | Thermocouple time constant: | .004 s |
| 8. | Time (crossflow velocity): | .01 s |
| 9. | Length (crossflow velocity): | .05 m |

Based on the above, the uncertainty of the flow rate of the jet was estimated to be 1.0 ml/s. Maximum uncertainty in the position of the probe's tip due to the uncertainty in deflection angle was determined to be .983 mm (.0387 in). Combined with the resolution of the positioning platform, the tip of the probe was positioned with an uncertainty of 1.135 mm (.0447 in) in each plane, or with an overall uncertainty of 1.605 mm (.063 in) in three-dimensional space. Temperature was measured at the approximate rate of 100 samples per second, well within the constraints of the thermocouple time constant. Uncertainty in the temperature measurements were governed by the resolution of the analog-to-digital converter which was .0099 °C. Uncertainty in the crossflow velocity was .00625 m/s (.0205 ft/sec).

APPENDIX B

MICROCOMPUTER PROGRAMS

## 1. MAIN_T

```
10   !    MAIN_T
20   !
30   !      This program coordinates the entire
40   !    data-taking evolution for measuring
50   !    temperature distributions in buoyant
60   !    jets.
70   !
80   !
90   !       1. Load all subprograms
100  !       2. Input desired positions from a
110  !          disk file of the form : "RUNEX"
120  !          (value "XX" is the run number)
130  !       3. Move the 3-D positioning
140  !          platform to each position
150  !       4. Align the thermocouple probe with
160  !          the jet streamwise axis
170  !       5. Obtain 200 temperatures at each
180  !          position and compute the mean and
190  !          standard deviation (sd)
200  !       6. Write to disk:
210  !           a. T(C)
220  !           b. sd
230  !           c. x,y,z in (mm)
240  !              nozzle centerline is (0,0.0)
250  !
260  !    Probe and arm dimensions in inches:
270  !       a. Shortest arm length = 20.0
280  !       b. Longest arm length  = 24.0
290  !
300  Length_probe=4.4375
310  Length_arm=20.0
320  !
330  OPTION BASE 1
340  DIM Coef(12),X(500),Y(500),Z(500),Probe_angle(500)
350  LOADSUB ALL FROM "T_SUBS"
360  LOADSUB ALL FROM "MTR_SUBS"
370  LOADSUB ALL FROM "PROBE_SUBS"
380  CALL Retrieve_coef(Coef(*),"motor_coef")
390  !
400  !   2. Input desired positions from disk
410  !
420      I=1
430      INPUT "Angle of arm relative to +Y-axis?",Angle_arm
440      INPUT "Filename for positioning data?",Filename$
450      ASSIGN @File4 TO Filename$
460 Go_on:        !
470               ENTER @File4;X(I),Y(I),Z(I)
480               !
490               IF X(I)<>-100 THEN
500                 IF X(I)=-999 THEN
510                    Probe_angle(I)=Y(I)
520                    P_angle=Y(I)
530                 ELSE
540                    Probe_angle(I)=P_angle
550                    I=I+1
560                 END IF
570                 !
580                 GOTO Go_on
590               END IF
600               !
```

```
610              !
620              GOTO Go_on
630            END IF
640            !
650            ASSIGN @File4 TO *
660            Nitems=I-1
670            !
680        !3. Begin loop to take data at each point
690        !
700        INPUT "NAME OF FILE WHERE DATA IS TO BE STORED?",Filename1$
710        Records=(Nitems*8*7/256)+2
720        CREATE BDAT Filename1$,Records
730        ASSIGN @File1 TO Filename1$
740        !
750        !
760        !
770        FOR I_position=1 TO Nitems
780            !
790            !a. Move milling machine and move the
800            !   thermocouple probe.
810            !
820            I=I_position
830         CALL Move_ldv_to(X(I),Y(I),Z(I),Lenght_arm,Length_probe,Angle_arm,
e_angle(I),Coef(*))
840            !
850            !
860            !b. Obtain mean temperature and sd
870            !
880            CALL T_couple(T,"PROBE","C",200,St_dev)
890            !
900            !c. Measure ambient and jet temps
910            !
920            CALL T_couple(T_ambient,"AMBIENT","C",10,Sd)
930            CALL T_couple(T_nozzle,"NOZZLE","C",10,Sd)
940            !
950            !d. Write all information to disk
960            !
970            OUTPUT @File1;X(I),Y(I),Z(I)
980            OUTPUT @File1;T,T_ambient,T_nozzle
990            OUTPUT @File1:St_dev
1000       NEXT I_position
1010       !
1020           !4. Close files
1030           !
1040           OUTPUT @File1;-100
1050           ASSIGN @File1 TO *
1060           !
1070           !5. Terminate program
1080           !
1090           PRINT "All done!"
1100           BEEP
1110           BEEP
1120  END
```

## 2. PROBE_SUBS

```
10    !  PROBE_SUBS
20    !
30    !   This program moves the temperature probe
40    ! to desired angles of deflection.
50    !
60    !   NOTE:  Calibration coefficients are
70    !          entered in SUB Read_angle,
80    !          beginning at line 290.
90    !
100   CALL Read_angle(Angle)
110      PRINT "The probe is presently at";Angle;" degrees from horizontal."
120   INPUT "What is your desired angle for the probe?",Desired_angle
130   CALL Probe_move(Desired_angle)
140   GOTO 120
150   END
160   !
170   !
180   !
190   SUB Read_angle(Actual_angle)
200       !This program reads the present angle
210       !of the probe and returns it.
220       ! 0 degrees = horizontal
230       !90 degrees = vertical, downward
240       !
250       !A0, A1 and A2 = coefficients for a
260       !second order curve fit of mV vs angle
270       !of deflection data.
280       !
290       !Coefficients for 8 June data follow:
300       !
310       A0=-23.8657824056449
320       A1=3.09995506283164E-2
330       A2=-1.22922305456149E-6
340       !                       ! FORMAT A/D CARD
350       OUTPUT 723;"CC,1T" !Clear Relay Card
360       OUTPUT 723;"CC,3T" !Clear A/D Card
370       OUTPUT 723;"CC,7T" !Clear Digital Card
380       OUTPUT 723;"SF,3,3,3,1.25,12T"
390       OUTPUT 723;"OB,1,10,1T" ! CLOSE RELAY
400       OUTPUT 723;"IP,3T"     ! START A/D
410       ENTER 72301;V
420       Actual_angle=A0+A1*V+A2*V*V
430   SUBEND
440   !
450   !
460   !
470   SUB Probe_move(Desired_angle)
480         !This subprogram moves the probe to the
490         !desired angle
500         !
510         !  0. Check to see if the angle is in
520         !      an acceptable range.
530         !
540            OUTPUT 723;"OP,1,0T" !Clear Relays
550            CALL Clear_screen
560            !
570            IF Desired_angle>90 THEN
580               BEEP 3400,.1
590               BEEP 1700,.1
```

```
600                BEEP 3400,1
610                PRINT "Desired angle exceeds 90 degrees!!!"
620                SUBEXIT
630             END IF
640             !
650             IF Desired_angle<0 THEN
660                BEEP 3400,1
670                BEEP 3800,1
680                BEEP 3600,1
690                PRINT "Desired angle is negative!!!"
700                SUBEXIT
710             END IF
720          !
730          !  1.a. Clear the digital output card.
740          !     b. Format the A/D card.
750          !     c. Close the relay that corrects
760          !        the probe potentiometer to the
770          !        A/D converter.
780          !
790            OUTPUT 723;"OP,7,0T"
800            OUTPUT 723;"SF,3,3,3,1.25,3T"
810            OUTPUT 723;"CC,1T"
820            OUTPUT 723;"OB,1,10,1T"
830          !
840          !  2. Define the acceptable tolerance
850          !     in the angle (degrees).
860          !
870            Tolerance=.5
880          !
890          !  3. Control loop.
900          !
910 Repeat:    CALL Read_angle(Actual_angle)
920            PRINT "ANGLE =";
930            PRINT USING "DDD.DD";Actual_angle
940              BEEP Actual_angle*100,.05
950            Angle_error=(Desired_angle-Actual_angle)
960            !
970            IF ABS(Angle_error)>Tolerance THEN
980               !
990               IF Angle_error>=0 THEN
1000                 Direction$="Down"
1010              ELSE
1020                 Direction$="Up"
1030              END IF
1040              !
1050              CALL Motor_go(Direction$)
1060              !
1070              GOTO Repeat
1080           END IF
1090 OUTPUT 723;"OP,7,0T"
1100 OUTPUT 723;"CC,1T"  !Clear relay card.
1110 SUBEND
1120 !
1130 !
1140 !
1150 SUB Motor_go(Direction$)
1160     IF Direction$="Up" THEN
1170        Lbit=8
1180     END IF
1190     !
```

```
1200      IF Direction$="Down" THEN
1210         Lbit=7
1220      END IF
1230      !
1240      OUTPUT 723;"OP,7";2^Lbit;"T"
1250 SUBEND
1260 !
1270 !
1280 !
1290 SUB Clear_screen
1300 ! Clear the CRT.
1310 !
1320    OUTPUT 2 USING "#,B";255,75
1330    GCLEAR
1340 SUBEND
```

## 3. MTR_SUBS

```
10    !   MTR_SUBS
20    !
30    !  The following series of subroutines
40    ! are utilized to calibrate the positioning
60    ! platform and ultimately to move the probe
70    ! tip to desired positions within the jet.
80    !
90    SUB Draw_flume
100   !
110   ! Draw the Buoyant Jet Flume on the CRT.
120   !
130   GCLEAR
140   GRAPHICS ON
150   WINDOW 0,48,0,38
160   LINE TYPE 1
170   MOVE 6,6
180   ! Draw the top view
190   IDRAW 36,0
200   IDRAW 0,10
210   IDRAW -36,0
220   IDRAW 0,-10
230   !
240   IMOVE 6,0
250   IDRAW 0,10
260   IMOVE 24,0
270   IDRAW 0,-10
280     ! label "Top".
290     MOVE 0,10
300     CSIZE 5
310     LABEL "Top"
320   ! Draw the side view.
330   MOVE 6,22
340   IDRAW 36,0
350   IDRAW 0,13
360   IDRAW -36,0
370   IDRAW 0,-13
380   IMOVE 6,0
390   IDRAW 0,13
400   IMOVE 24,0
410   IDRAW 0,-13
420     ! label "Side"
430     CSIZE 5
440     MOVE 0,29
450     LABEL "Side"
460   !
470   ! Label the picture.
480   !
490     MOVE 11,35
500     CSIZE 7
510     LABEL "BUOYANT JET FLUME"
520   !
530   ! Put on the nozzle.
540   !
550   MOVE 14,22
560   IDRAW 0,2
570   IDRAW .25,0
580   IDRAW 0,-2
590   !
600   IMOVE 0,-2
610   CSIZE 3
```

```
620    LABEL "nozzle"
630    !
640    MOVE 14,11
650    CSIZE 3
660    LABEL "o"
670    !
680    ! Indicate the direction of flow.
690    !
700    MOVE 8,11
710    IDRAW 2,0
720    IDRAW -.5,-.5
730    IDRAW .5,.5
740    IDRAW -.5,.5
750    !
760    MOVE 8,27
770    IDRAW 2,0
780    IDRAW -.5,-.5
790    IDRAW .5,.5
800    IDRAW -.5,.5
810    !
820    SUBEND
830    !
840    !
850    !
860    !
870    !
880    !
890    SUB Calibrate(Filename$)
900    !
910      OPTION BASE 1
920      DIM Coef(12)
930    !
940    !   Calibrate the positioners on the
950    !   milling machine movement.
960    !   Onto disk, write out the calibration
970    !   coefficients and the hard boundaries
980    !   that must be observed!
990    !   This file will be called "Motor_coef".
1000   !
1010   ! A.  Position the probe volume at the
1020   !      wall of the tip of the nozzle. This
1030   !      position is (0,0,0).  All readings
1040   !      will be in inches.  Read all three
1050   !      potentiometers.  Ask the user for the
1060   !      nozzle outer diameter and compute the
1070   !      zero position.  Ask the user for the
1080   !      milling machine readings.
1090   !
1100   ! B.  Next, move the bed to some new posi-
1110   !      tion using the override switches.
1120   !      Take readings from the pots and ask
1130   !      for the milling machine readings.
1140   !      Compute the calibration coefficients.
1150   !
1160   ! C.  Move the bed to each of the extremes
1170   !      in the X, Y, and Z directions using
1180   !      the override switches and have the
1190   !      user tell the computer when each of
1200   !      these boundaries are hit.  Enter each
1210   !      of these onto the disk file.
```

```
1220  !
1230  ! D.  Disk file "Motor_coef":
1240  !
1250  !      1.  x_zero, x_slope
1260  !      2.  y_zero, y_slope
1270  !      3.  z_zero, z_slope
1280  !      4.  x_min, x_max
1290  !      5.  y_min, y_max
1300  !      6.  z_min, z_max
1310  !
1320  BEEP
1330     PRINTER IS 1
1340     GCLEAR
1350     OUTPUT 2 USING "#,B";255,75
1360     !
1370  PRINT "I. POTENTIOMETER CALIBRATION:        "
1380  PRINT "                                     "
1390  PRINT "   NOTE: 1. Probe must be horizontal"
1400  PRINT "         2. Arm must be parallel to "
1410  PRINT "            the bed axis            "
1420  PRINT "         3. ALPHA = BETA            "
1430  PRINT "                                     "
1440  PRINT "  A. Using the override switches,   "
1450  PRINT "     position the probe volume at   "
1460  PRINT "     the outer wall of the tip of   "
1470  PRINT "     the nozzle.                    "
1480  PRINT "                                     "
1490  PRINT "  B. I will need the nozzle O.D. and"
1500  PRINT "     the milling machine positon.   "
1510  PRINT "                                     "
1520  PRINT "{ Hit <cont>}                        "
1530  PAUSE
1540  BEEP 1500,.1
1550  INPUT "1. Nozzle O.D. (inches)?",Nozzle_od
1560  BEEP 2000,.1
1570  INPUT "2. X (in), {+ into flume}?",X_1
1580  BEEP 2500,.1
1590  INPUT "3. y (in), {+ along flume to the right}?",Y_1
1600  BEEP 3000,.1
1610  INPUT "4. z (in), {+ upward}?",Z_1
1620  !
1630  CALL Read_pot("X",Vx_1)
1640  CALL Read_pot("Y",Vy_1)
1650  CALL Read_pot("Z",Vz_1)
1660  !
1670  !
1680    CALL Clear_screen
1690  PRINT "C. Move the milling machine to a new"
1700  PRINT "   position in 3-D, by at least 5   "
1710  PRINT "   inches in each direction.        "
1720    BEEP 3200,.1
1730  INPUT "X, Y, Z in inches?",X_2,Y_2,Z_2
1740    CALL Read_pot("X",Vx_2)
1750    CALL Read_pot("Y",Vy_2)
1760    CALL Read_pot("Z",Vz_2)
1770  !
1780  ! C.  Calculate the calibration coefficients
1790  !
1800    X_zero=-((Nozzle_od/2)+Vx_1*((X_2-X_1)/(Vx_2-Vx_1)))
1810    X_slope=(X_2-X_1)/(Vx_2-Vx_1)
```

```
1820      !
1830      Y_zero=-Vy_1*(Y_2-Y_1)/(Vy_2-Vy_1)
1840      Y_slope=(Y_2-Y_1)/(Vy_2-Vy_1)
1850      !
1860      Z_zero=-Vz_1*(Z_2-Z_1)/(Vz_2-Vz_1)
1870      Z_slope=(Z_2-Z_1)/(Vz_2-Vz_1)
1880      !
1890    !
1900    ! D. Find the physical boundaries for each
1910    !     direction.
1920    !
1930      CALL Clear_screen
1940    PRINT "1. Move the milling machine to the  "
1950    PRINT "    minimum value of 'x'. Hit <cont>."
1960    PRINT "(Away from the flume, backwards)     "
1970    PAUSE
1980      CALL Read_pot("X",V)
1990        X_min=X_zero+X_slope*V
2000    PRINT "2. Move the milling machine to the  "
2010    PRINT "    maximum value of 'x'.  (Towards  "
2020    PRINT "    the flume).  Hit <cont>.         "
2030    PAUSE
2040      CALL Read_pot("X",V)
2050        X_max=X_zero+X_slope*V
2060    PRINT "3. Move the milling machine to the  "
2070    PRINT "    minimum value of 'y'. Hit <cont>."
2080    PRINT "(To the left along the flume)        "
2090    PAUSE
2100      CALL Read_pot("Y",V)
2110        Y_min=Y_zero+Y_slope*V
2120    PRINT "4. Move the milling machine to the  "
2130    PRINT "    maximum value of 'y'. Hit <cont>."
2140    PAUSE
2150      CALL Read_pot("Y",V)
2160        Y_max=Y_zero+Y_slope*V
2170    PRINT "5. Move the milling machine to the  "
2180    PRINT "    minimum value of 'z'. Hit <cont>."
2190    PRINT "(Downwards)"
2200    PAUSE
2210      CALL Read_pot("Z",V)
2220        Z_min=Z_zero+Z_slope*V
2230    PRINT "6. Move the milling machine to the  "
2240    PRINT "    maximum value of 'z'. Hit <cont>."
2250    PAUSE
2260      CALL Read_pot("Z",V)
2270        Z_max=Z_zero+Z_slope*V
2280    !
2290    ! E. Write out the file "Motor_coef".
2300    !
2310    ON ERROR GOTO Purge_file
2320   Reenter: CREATE BDAT Filename$,1
2330    ASSIGN @File TO Filename$
2340    !
2350      OUTPUT @File;X_zero,X_slope
2360      OUTPUT @File;Y_zero,Y_slope
2370      OUTPUT @File;Z_zero,Z_slope
2380      !
2390      OUTPUT @File;X_min,X_max
2400      OUTPUT @File;Y_min,Y_max
2410      OUTPUT @File;Z_min,Z_max
```

```
2420     !
2430     ASSIGN @File TO *
2440     SUBEXIT
2450 Purge_file:  PURGE Filename$
2460              GOTO Reenter
2470     !
2480   SUBEND
2490   !
2500   !
2510   !
2520   !
2530   !
2540   !
2550   SUB Read_pot(Direction$,Value)
2560   !
2570   !
2580   ! Read one potentiometer and return a volt-
2590   !  age.
2600   !
2610   !  R3 -- Pot X
2620   !  R4 -- Pot Y
2630   !  R5 -- Pot Z
2640   !
2650   !
2660   IF Directin$="X" THEN Relay=3
2670   IF Direction$="Y" THEN Relay=4
2680   IF Direction$="Z" THEN Relay=5
2690   !
2700   !
2710      OUTPUT 723;"OP,1,0T"
2720      OUTPUT 723;"OB,1,";Relay;",1T"
2730   !
2740   OUTPUT 723;"IP,3T"
2750   ENTER 72301;Value
2760   !
2770   !
2780   SUBEND
2790   !
2800   !
2810   !
2820   !
2830   !
2840   !
2850   SUB Clear_screen
2860   !  Clear the CRT.
2870   !
2880      OUTPUT 2 USING "#,B";255,75
2890      GCLEAR
2900   SUBEND
2910   !
2920   !
2930   !
2940   !
2950   !
2960   !
2970   SUB Motor(Direction$,Rotation$)
2980   !
2990   !  Turn on the motor in the requested direc-
3000   !     tion (x,y,z) with the requestion rota-
3010   !     tion (CW, CCW).
```

```
3020  !
3030    Dir$=Direction$
3040    Rot$=Rotation$
3050    IF Dir$="X" AND Rot$="CW" THEN Lbit=2
3060    IF Dir$="X" AND Rot$="CCW" THEN Lbit=1
3070    IF Dir$="Y" AND Rot$="CW" THEN Lbit=4
3080    IF Dir$="Y" AND Rot$="CCW" THEN Lbit=3
3090    IF Dir$="Z" AND Rot$="CCW" THEN Lbit=5
3100    IF Dir$="Z" AND Rot$="CW" THEN Lbit=6
3110    !
3120    !
3130    OUTPUT 723;"OP,7,";2^Lbit;"T"
3140  SUBEND
3150  !
3160  !
3170  !
3180  !
3190  !
3200  !
3210  SUB Motor_stop
3220  !
3230  !  Stop all motors!
3240  !
3250    OUTPUT 723:"OP,7,0T"
3260  SUBEND
3270  !
3280  !
3290  !
3300  !
3310  !
3320  !
3330  SUB Retrieve_coef(Coef(*),Filename$)
3340  !
3350    OPTION BASE 1
3360  !
3370  !  Retrieve the potentiometer calibration
3380  !    coefficients from a disk file called
3390  !    "Motor_coef".  Place these in an array.
3400  !
3410    ASSIGN @File TO Filename$
3420    !
     3430    FOR I=1 TO 12 STEP 2
3440      ENTER @File;Coef(I),Coef(I+1)
3450    NEXT I
3460    !
3470    ASSIGN @File TO *
3480  SUBEND
3490  !
3500  !
3510  !
3520  !
3530  !
3540  !
3550  SUB Label_point(X,Y,Z,Symbol$)
3560  !
3570  !  Label a point on the Flume diagram
3580  !    using the symbol specified.
3590  !
3600     PRINT TABXY(1,13),"(X,Y,Z) inches = ";
3610     PRINT USING "DDD.DDD":X,Y,Z
```

```
3620     !
3630     !
3640     IF Symbol$="X" THEN
3650       !
3660       MOVE 14+Y,24+Z
3670         IMOVE -.2,-.2
3680         IDRAW 0,.4
3690         IDRAW .4,0
3700         IDRAW 0,-.4
3710         IDRAW -.4,0
3720       !
3730       MOVE 14+Y,11+X
3740         IMOVE -.2,-.2
3750         IDRAW 0,.4
3760         IDRAW .4,0
3770         IDRAW 0,-.4
3780         IDRAW -.4,0
3790     END IF
3800     !
3810     IF Symbol$="+" THEN
3820       !
3830       MOVE 14+Y,11+X
3840         IMOVE 0,.2
3850         IDRAW -.2,-.4
3860         IDRAW .4,0
3870         IDRAW -.2,.4
3880       !
3890       MOVE 14+Y,24+Z
3900         IMOVE 0,.2
3910         IDRAW -.2,-.4
3920         IDRAW .4,0
3930         IDRAW -.2,.4
3940     END IF
3950   SUBEND
3960   !
3970   !
3980   !
3990   !
4000   !
4010   !
4020   SUB Move_ldv_to(X,Y,Z,Length_arm,Length_probe,Angle_arm,Angle_probe,Cc
))
4030   DEG
4040   !
4050     OUTPUT 723;"CC,1T"
4060     OUTPUT 723;"SF,3,3,3,1.25,12T"
4070     PRINTER IS 1
4080     ON KEY 0 LABEL "ABORT" CALL Stop_all
4090     OPTION BASE 1
4100     Tolerance=.006
4110   !
4120   !  Move the probe to the position indicated
4130   !  in (inches) relative to the nozzle tip.
4140   !
4150   !  Dimensions are in inches and degrees
4160   !
4170   !  A.1  Load in the calibration coefficients.
4180   !
4190       X_zero=Coef(1)
4200       X_slope=Coef(2)
```

```
4210       Y_zero=Coef(3)
4220       Y_slope=Coef(4)
4230       Z_zero=Coef(5)
4240       Z_slope=Coef(6)
4250       X_min=Coef(7)
4260       X_max=Coef(8)
4270       Y_min=Coef(9)
4280       Y_max=Coef(10)
4290       Z_min=Coef(11)
4300       Z_max=Coef(12)
4310     !
4320     !  A.2 Move the probe
4330     !
4340     CALL Probe_moe(Angle_probe)
4350     !
4360     !  B.  Does (X,Y,Z) lie within the per-
4370     !      mitted boundaries?
4380     !
4390       IF X>X_max OR X<X_min OR Y>Y_max OR Y<Y_min OR Z>Z_max OR Z<Z_min THEN

4400          BEEP 1700,.5
4410          BEEP 2000,.5
4420          BEEP 1700,.5
4430          BEEP 2000,.5
4440          PRINT "Desired point is out of range!"
4450          SUBEXIT
4460       END IF
4470     !
4480     ! C.  Find out where the probe is now, draw
4490     !     the flume on the CRT, and label the
4500     !     desired position.
4510     !
4520     !  1.  Sound warning, movement immenent!
4530     !
4540        CALL Clear_screen
4550        PRINT TABXY(1,12),"MOVEMENT OF MILLING MACHINE IMMINENT!!!"
4560          FOR I=1 TO 4
4570            BEEP 1200,.1
4580            BEEP 1700,.1
4590            BEEP 2200,.1
4600            BEEP 2700,.1
4610          NEXT I
4620          CALL Clear_screen
4630        !
4640        !
4650        OUTPUT 723;"CC,1T"   !CLEAR RELAY CARD.
4660     CALL Position("X",X_actual,Valu_shaft,Length_arm,Length_probe,Angle_arm,
Angle_probe,Coef(*))
4670     CALL Position("Y",Y_actual,Valu_shaft,Length_arm,Length_probe,Angle_arm,
Angle_probe,Coef(*))
4680     CALL Position("Z",Z_actual,Valu_shaft,Length_arm,Length_probe,Angle_arm,
Angle_probe,Coef(*))
4690        !
4700        !
4710        CALL Draw_flume
4720        CALL Label_point(X_actual,Y_actual,Z_actual,"+")
4730        CALL Label_point(X,Y,Z,"X")
4740     !
4750     !  D.  Move each motor to bring the error
4760     !      between actual and desired position
```

```
4770    !       into tolerance.
4780    !
4790          X_old=X_actual
4800 X_node: Xerror=X-X_actual
4810          IF ABS(Xerror)>Tolerance THEN
4820            IF Xerror>0 THEN Rot$="CCW"
4830            IF Xerror<0 THEN Rot$="CW"
4840              CALL Motor("X",Rot$)
4850    CALL Position("X",X_actual,Valu_shaft,Length_arm,Length_probe,Angle_a
Angle_probe,Coef(*))
4860              CALL Plot_path(X_old,Y_actual,Z_actual,X_actual,Y_actual,Z_ac
al)
4870                  X_old=X_actual
4880            GOTO X_node
4890          END IF
4900 !
4910 !
4920          Y_old=Y_actual
4930 Y_node: Yerror=Y-Y_actual
4940          IF ABS(Yerror)>Tolerance THEN
4950            IF Yerror>0 THEN Rot$="CCW"
4960            IF Yerror<0 THEN Rot$="CW"
4970              CALL Motor("Y",Rot$)
4980    CALL Position("Y",Y_actual,Valu_shaft,Length_arm,Length_probe,Angle_a
Angle_probe,Coef(*))
4990              CALL Plot_path(X_actual,Y_old,Z_actual,X_actual,Y_actual,Z_a
al)
5000                  Y_old=Y_actual
5010            GOTO Y_node
5020          END IF
5030 !
5040 !
5050          Z_old=Z_actual
5060 Z_node: Zerror=Z-Z_actual
5070          IF ABS(Zerror)>Tolerance THEN
5080            IF Zerror>0 THEN Rot$="CW"
5090            IF Zerror<0 THEN Rot$="CCW"
5100              CALL Motor("Z",Rot$)
5110    CALL Position("Z",Z_actual,Valu_shaft,Length_arm,Length_probe,Angle_a
Angle_probe,Coef(*))
5120              CALL Plot_path(X_actual,Y_actual,Z_old,X_actual,Y_actual,Z_a
al)
5130              Z_old=Z_actual
5140            GOTO Z_node
5150          END IF
5160 !
5170 !
5180    CALL Motor_stop
5190 !
5200 !
5210    FOR I=1 TO 4
5220       BEEP 2400,.2
5230       BEEP 4800,.2
5240    NEXT I
5250 !
5260 SBEND
5270 !
5280 !
5290 !
5300 !
```

```
5310 !
5320 !
5330 SUB Position(Direction$,Value,Valu_shaft,Length_arm,Length_probe,Angle_arm,
Angle_probe,Coef(*))
5340   !
5350   OPTION BASE 1
5360   DEG
5370   !
5380   !  Return the position (inches) for the
5390   !    appropriate direction relative to the
5400   !    nozzle tip.
5410   !
5420      CALL Read_pot(Direction$,Voltage)
5430   !
5440      X_zero=Coef(1)
5450      X_slope=Coef(2)
5460      Y_zero=Coef(3)
5470      Y_slope=Coef(4)
5480      Z_zero=Coef(5)
5490      Z_slope=Coef(6)
5500   !
5510   !
5520      Dir$=Direction$
5530      !
5540      IF Dir$="X" THEN
5550         Valu_shaft=X_zero+X_slope*Voltage
5560         Value=Valu_shaft-Length_arm*COS(Angle_arm)*TAN(45-Angle_arm/2.0)
5570      END IF
5580      !
5590      IF Dir$="Y" THEN
5600         Valu_shaft=Y_zero+Y_slope*Voltage
5610         Value=Valu_shaft+Length_probe*(1.-COS(Angle_probe))+Length_arm*COS(
Angle_arm)
5620      END IF
5630      !
5640      IF Dir$="Z" THEN
5650         Valu_shaft=Z_zero+Z_slope*Voltage
5660         Value=Valu_shaft-Length_probe*SIN(Angle_probe)
5670      END IF
5680      !
5690  SUBEND
5700  !
5710  !
5720  !
5730  !
5740  !
5750  !
5760  SUB Stop_all
5770  !  STOP ALL MOTORS AND QUIT
5780  !
5790     GCLEAR
5800     CALL Motor_stop
5810     PRINT "MOTOR CONTROL ABORTED!!!"
5820     PRINT "(HIT <CONT> TO CONTINUE)"
5830     PAUSE
5840  SUBEND
5850  !
5860  !
5870  !
5880  !
```

```
5890  !
5900  !
5910  SUB Plot_path(X1,Y1,Z1,X2,Y2,Z2)
5920  !
5930  !  Plot the path of the probe on the flume
5940  !    diagram as the motors move the bed.
5950  !
5960  ! Lower plot followed by upper plot.
5970  !
5980     PRINT TABXY(1,13),"(X,Y,Z) inches = ";
5990     PRINT USING "DD.DDD";X2,Y2,Z2
6000     MOVE 14+Y1,24+Z1
6010     DRAW 14+Y2,24+Z2
6020     !
6030     MOVE 14+Y1,11+X1
6040     DRAW 14+Y2,11+X2
6050     !
6060  SUBEND
```

4. T_SUBS

```
10    !   T_SUBS
20    !
30    !
40    SUB T_couple(Temperature,Choice$,Scale$,No_readings,Stdev)
50    !
60    !  SUBPROGRAM T_COUPLE
70    !
80    !  by Bill Culbreth
90    !  19 April 1984
100   !
110   !  PURPOSE:  This program is designed to
120   !     read type T or E thermocouples and
130   !     return the actual temperature to
140   !     the calling routine.
150   !
160   !  Temperature -- Temperature from the
170   !     thermocouple in degrees F or C from
180   !     the thermocouple identified by
190   !     "Choice$".
200   !  Choice$ -- Thermocouple choice, current-
210   !     ly:  "AMBIENT", "NOZZLE", or, "PROBE".
220   !  Scale$  -- "F" for Fahrenheit or "C" for
230   !     Celsius, or "H" for histogram in "C".
240   !  No_readings -- How many readings of the
250   !     same thermocouple should the routine
260   !     take?
270   !  Stdev -- The standard deviation of the
280   !     temperature for the indicated number
290   !     of readings in the units given by
300   !     "Scale$".
310   !
320   !
330   !  1.  Open all relays and initialize the
340   !      A/D converter.
350   !
360      OUTPUT 723;"CC,1T"
370      OUTPUT 723;"SF,3,3,3,1.25,12T"
380      !
390      OUTPUT 723;"OP,1,0T"
400   !
410   !  2.  Close the chosen relays.
420   !
430   !    a.  Ambient T -- Type T, relays 6,8.
440   !    b.  Nozzle  T -- Type T, relays 7,8.
450   !    c.  Probe   T -- Type E, relay  9.
460   !
470      IF Scale$="H" THEN
480         ! Plot a histogram using Celsius.
490         Histogram$="YES"
500         Scale$="C"
510      ELSE
520         Histogram$="NO"
530      END IF
540      !
550      !
560      IF Choice$="AMBIENT" THEN
570         Type$="T"
580         OUTPUT 723;"OB,1,6,1,8,1T"
590      END IF
600      !
```

```
610       IF Choice$="NOZZLE" THEN
620          Type$="T"
630          OUTPUT 723;"OB,1,7,1,8,1T"
640       END IF
650       !
660       IF Choice$="PROBE" THEN
670          Type$="E"
680          OUTPUT 723;"OB,1,9,1T"
690       END IF
700       !
710    !
720    !  3.  Take an A/D conversion and convert
730    !       into temperature.
740    !
750       Sum=0
760       Sum1=0
770    !
780       WAIT 1
790       IF Histogram$="YES" THEN GOSUB Set_up_histo
800       !
810       !
820       FOR I=1 TO No_readings
830          OUTPUT 723;"IP,3T"
840          ENTER 72301;A
850             IF Type$="T" THEN
860                A=A/1000
870             END IF
880             IF Type$="E" THEN
890                A=A/1000
900             END IF
910      !             PRINT "V(mV) = ";A
920          GOSUB Convert_t
930      !             BEEP A*100,.01
940            Sum=Sum+A
950            Sum1=Sum1+A*A
960            !
970            IF Histogram$="YES" THEN GOSUB Plot_point
980            !
990       NEXT I
1000   !
1010      Temperature=Sum/No_readings
1020      !
1030      !
1040      IF No_readings=1 THEN
1050         Stdev=0
1060      ELSE
1070         Stdev=SQR(ABS((Sum1-No_readings*Temperature^2)/(No_readings-1)))
1080      END IF
1090   !
1100   !  4.  Open all relays.
1110   !
1120      OUTPUT 723;"OP,1,0T"
1130   !
1140   SUBEXIT
1150   !
1160   !
1170   !
1180 Convert_t:     !
1190                !  This subroutine converts (mV)
1200                !  from a thermocouple into Temp-
```

```
1210              ! erature.
1220              !
1230  !
1240  IF Type$="T" THEN
1250    A=2.5661297E+1*A-6.1954869E-1*A*A+2.2181644E-2*A^3-3.55009E-4*A^4
1260  END IF
1270  !
1280  !
1290  IF Type$="E" THEN
1300    A=1.7022525E+1*A-2.2097240E-1*A*A+5.4809314E-3*A^3-5.7669892E-5*A^4
1310  END IF
1320  !
1330  !  Fix the scale.
1340  !
1350     IF Scale$="F" THEN A=1.8*A+32
1360  RETURN
1370  !
1380  !
1390  !   .
1400  !
1410  !
1420  !
1430 Set_up_histo:  !
1440       !
1450       !  Set up a histogram of temperature
1460       !  versus number of counts.
1470       !
1480       !  1. Zero out the Height(*) array.
1490       !
1500       DIM Height(203)
1510       !
1520       FOR I=1 TO 202
1530         Height(I)=0
1540       NEXT I
1550       !
1560       !
1570       DUMP DEVICE IS 701
1580       GINIT
1590       OUTPUT 2 USING "#,B";255,75
1600       GRAPHICS ON
1610       FRAME
1620       WINDOW -100,100,-10,100
1630       MOVE -65,92
1640         CSIZE 7
1650         LABEL "TEMPERATURE HISTOGRAM"
1660         AXES 25,10,0,0,4,5,3
1670         PEN -1
1680         MOVE 0,-10
1690         DRAW 0,0
1700         MOVE 0,90
1710         DRAW 0,100
1720         PEN 1
1730      !
1740      !  Take 10 temperature readings to get
1750      !    the scale.
1760      !
1770         Sum=0
1780         Sum1=0
1790      FOR I=1 TO 10
1800         OUTPUT 723;"IP,3T"
```

```
1810          ENTER 72301:A
1820       NEXT I
1830       !
1840       FOR I=1 TO 100
1850          OUTPUT 723;"IP,3T"
1860          ENTER 72301:A
1870          IF Type$="T" THEN
1880             A=A/1000
1890          END IF
1900          IF Type$="E" THEN
1910             A=A/1000
1920          END IF
1930          GOSUB Convert_t
1940          Sum=Sum+A
1950          Sum1=Sum1+A*A
1960       NEXT I
1970          T_mean=Sum/100
1980          Sd=SQR(ABS(Sum1-100*T_mean^2)/99)
1990          !
2000          !  Change the window to extent from
2010          !      -4*Sd to +4*Sd.
2020          !
2030          MOVE -12,-7
2040          CSIZE 4
2050          LABEL USING "DDD.DD";T_mean
2060          MOVE 15,-7
2070          LABEL "C"
2080          !
2090          MOVE -87,-7
2100          LABEL USING "DDD.DD";T_mean-3*Sd
2110          MOVE 63,-7
2120          LABEL USING "DDD.DD";T_mean+3*Sd
2130          !
2140          !
2150          MOVE 5,47
2160          LABEL "50"
2170          !
2180          !
2190          !  3. Calculate the window temper-
2200          !     ature interval.
2210          !
2220          Interval=4*Sd/100
2230          !
2240          T_min=T_mean-4*Sd
2250          T_max=T_mean+4*Sd
2260          !
2270          WINDOW T_min,T_max,-10,100
2280    RETURN
2290    !
2300    !
2310    !
2320    !
2330    !
2340    !
2350  Plot_point:  !
2360       !
2370       ! Plot each temperature point as
2380       !    received on the histogram.
2390       !
2400       Freq=((A-T_min)/(T_max-T_min))*3000+1000
```

```
2410      BEEP Freq,.01
2420         J=0
2430         !
2440      FOR T=T_min TO T_max STEP Interval
2450         J=J+1
2460         IF A<=T THEN
2470            Height(J)=Height(J)+1
2480            GOTO Continue
2490         END IF
2500      NEXT T
2510      !
2520      !  Draw the point.
2530      !
2540 Continue:      !
2550         !
2560         !
2570         MOVE A,Height(J)
2580         CSIZE 4
2590         LABEL "."
2600      !
2610      !  Label the number of points and
2620      !    the temperature.
2630      !
2640         PRINT TABXY(2,3);"T(C)=";A
2650         PRINT TABXY(2,5);"Sample #";I
2660      !
2670  RETURN
2680  !
2690  !
2700  !
2710  !
2720  !
2730  !
2740  SUBEND
```

5. T_CAL

```
10   !   T_CAL
20   !
30   !This program records the output from the
40   !ambient, probe and nozzle themocouples
50   !for calibration purposes.  The data is
60   !printed as well as transmitted to a data
70   !file.
80   !
90   !Data is recorded in the following order:
100  !         a. Ambient temperature
110  !         b. Probe temperature
120  !         c. Nozzle temperature
130  !
140  !Place the ambient, probe and nozzle
150  !thermocouples into a bucket of warm water,
160  !execute this program, then add ice.
170  !
180  !
190  LOADSUB ALL FROM "T_SUBS"
200  !
210  !  Identify the BDAT file
220  !
230  INPUT "NAME OF FILE WHERE DATA IS TO BE STORED?",Filename1$
240  !
250  !  Identify the number of data points desired
260  !
270  INPUT "NUMBER OF DATA POINTS DESIRED?",Nitems
280  !
290  !  Identify the number of samples per
300  !  thermocouple per data point
310  !
320  INPUT "NUMBER OF SAMPLES PER DATA POINT?",Sample
330  !
340  !  Initialize a counter
350  !
360  I=1
370  !
380  !  Create a data file
390  !
400  Records=(Nitems*8*3/256)+2
410  CREATE BDAT Filename1$,Records
420  ASSIGN @File1 TO Filename1$
430  !
440  !  Take data and print results
450  !
460  CALL T_couple(T_ambient,"AMBIENT","C",Sample,Sd)
470  BEEP I*50,.05
480  PRINT "TAMB,SD=";T_ambient,Sd
490  CALL T_couple(T,"PROBE","C",Sample,St_dev)
500  BEEP I*50,.05
510  PRINT "TPROBE,SD=";T,St_dev
520  CALL T_couple(T_nozzle,"NOZZLE","C",Sample,Sd)
530  BEEP I*50,.05
540  PRINT "TNOZL,SD=";T_nozzle,Sd
550  !
560  !  Send data to the data file
570  !
580  OUTPUT @File1;T_ambient,T,T_nozzle
590  !
600  !  Test to see if finished
```

```
610  !
620  IF I=Nitems THEN
630     GOTO 760
640  ELSE
650     I=I+1
660     GOTO 460
670  END IF
680  !
690  !  Close the data file
700  !
710  OUTPUT @File1;-100
720  ASSIGN @File1 TO *
730  !
740  !  Alert the user...the job is completed
750  !
760  PRINT "ALL DONE"
770  BEEP
780  BEEP
790  END
```

6. PROBE_CAL

```
10    !   PROBE_CAL
20    !
30    !   This program will provide the data
40    ! necessary to calibrate probe deflection
50    ! if used in the following manner:
60    !
70    !   a. Switch OFF probe actuation power
80    !      at the probe base.
90    !
100   !   b. Swing the probe arm out of the
110   !      tank such that the probe is
120   !      accessable.
130   !
140   !   c. Attach the calibration panel to the
150   !      probe assembly, taking care not to
160   !      damage the glass probe.
170   !
180   !   d. Run the program...it will ask for
190   !      the desired position in mV.  The
200   !      following guidelines apply:
210   !
220   !           i. If it is desired to lower
230   !              the probe, type the extreme
240   !              value 9000 (anything >4600
250   !              will work, but 9000 is a
260   !              quick and easy number to
270   !              enter).
280   !
290   !          ii. If it is desired to raise
300   !              the probe, enter the extreme
310   !              value 90 (anything less than
320   !              940 will work).
330   !
340   !   e..The program will next ask which bit
350   !      is selected to be "high".  The
360   !      following guidelines apply:
370   !
380   !           i. If it is desired to lower the
390   !              probe, enter 7.
400   !
410   !          ii. If it is desired to raise the
420   !              probe, enter 8.
430   !
440   !   f. Switch ON probe activation power and
450   !      when the probe reaches a desired'
460   !      degree of deflection, switch the
470   !      activation power OFF and record the
480   !      mV value printed on the screen.
490   !
500   !   g. Repeat steps (d) through (f) until
510   !      sufficient data is collected.  Load
520   !      this data into the program "POLYFIT"
530   !      and request a second order fit
540   !      (let X=angle and Y=mV).
550   !      Enter the coefficients derived by
560   !      this program into the appropriate
570   !      location in the program "PROBE_SUBS".
580   !
590   !
600   !   NOTE:  The relays will be activated on
```

```
610   !     digital low!  When the machine boots
620   !     up (hp-9826), all relay lines are
630   !     high (+5V).  The instructions below
640   !     will drop the voltage to zero.
650   !
660   INPUT "What is the desired position? (mV)",Voltage
670   PRINT "Desired position (mV) =";Voltage
680   !
690   !Read the actual motor position.
700   !  If the desired position is BELOW the
710   !  actual position, then tell the motor
720   !  to move UP.
730   !  If it is ABOVE, then tell it to go DOWN.
740   !
750   !
760   INPUT "WHICH BIT DO YOU WANT HIGH?",Lbit
770   !
780   !
790     OUTPUT 723;"OP,7,0T" !CLEAR ALL D/O
800     OUTPUT 723;"OP,7,";2^Lbit;"T"
810     !
820     OUTPUT 723;"CC,1T" !CLEAR A/D CARD
830     !
840   OUTPUT 723;"SF,3,3,3,1.25,12T" !FORMAT A/D
850   OUTPUT 723;"OB,1,10,1T" !CLOSE THE RELAY
860                           !THAT CONNECTS THE
870                           !A/D CARD TO THE
880                           !POTENTIOMETER
890   OUTPUT 723;"IP,3T" !START A/D CONVERSION
900   ENTER 72301;A      !ENTER A/D VALUE INTO A.
910   DISP A
920   BEEP ABS(A),.01
930   !
940   !  The following IF stops the motor when
950   !  it reaches it´s limits.
960   !
970   IF (Lbit=7 AND A>4600) OR (Lbit=8 AND A<940) THEN
980      OUTPUT 723;"OP,7,0T"
990      BEEP
1000     PRINT "ALL DONE!!!"
1010  END IF
1020  GOTO 890
1030  END
```

## 7. MOTOR_CAL

```
10     !   MOTOR_CAL
20     !
30     !  PURPOSE:  Calibrate the potentiometers
40     !     used with the motors on the milling
50     !     machine.
60     !
70     !
80     OPTION BASE 1
90     DIM Coef(12)
100    !
110    OUTPUT 723;"SF,3,3,3,1,25,12T"
120    LOADSUB ALL FROM "MTR_SUBS"
130    LOADSUB ALL FROM "PROBE_SUBS"
140    File$="motor_coef"
150    !
160    CALL Calibrate(File$)
170    !
180    CALL Retrieve_coef(Coef(*),File$)
190      BEEP 2400,1
200    !
210    !
220    PRINT "What (x,y,z) position do you wish to"
230    PRINT "  move to? (inches relative to noz-"
240    PRINT "  zle)"
250    INPUT X,Y,Z
260    !
270    CALL Move_ldv_to(X,Y,Z,Length_arm,Length_probe,Angle_arm,Probe_angle,Coe
*))
280    !
290    BEEP
300    GOTO 280
310    END
```

## 8. LOAD_XYZ

```
10      !  LOAD_XYZ
20      !
30      !  by Bill Culbreth
40      !
50      !  30 April 1984
60      !
70      !
80      !  PURPOSE: This program will allow the
90      !     user to enter desired (x,y,z) posi-
100     !     tions of the milling machine relative
110     !     to the nozzle.  The values will be
120     !     stored on disk to be utilized later
130     !     by MAIN_T.
140     !
150     DIM X(500),Y(500),Z(500)
160     !
170     !  1.  Input the file name.
180     !
190        GOSUB Clear_screen
200     !
210        PRINTER IS 1
220        PRINT "Input the file name."
230        PRINT "( I suggest 'RUNXX' where 'XX'"
240        PRINT "  is the run number.          )"
250        PRINT
260        INPUT Filename$
270        !
280     !
290     !  2.  Begin inputting data.
300     !
310     !
320        GOSUB Clear_screen
330        !
340        PRINT "Do you wish to append a previous data file?"
350        INPUT Answer$
360        !
370        IF Answer$="YES" THEN
380           INPUT "Previous file name?",Old_file$
390           ASSIGN @File1 TO Old_file$
400           !
410           I=0
420 Loop1: !
430           I=I+1
440           ENTER @File1;X(I),Y(I),Z(I)
450           OUTPUT 701;"I,X,Y,Z=";I,X(I),Y(I),Z(I)
460           IF X(I)<>-100 THEN GOTO Loop1
470           ASSIGN @File1 TO *
480           PURGE Old_file$
490           Count=I-1
500        ELSE
510           Count=0
520        END IF
530           !
540        GOSUB Clear_screen
550        BEEP
560        !
570        PRINT "1. Input the desired position in "
580        PRINT "   inches as X, Y, and Z."
590        PRINT
600        PRINT "2. Terminate input by entering '-100'"
```

```
610       PRINT "2. Terminate input by entering '-100'"
620       PRINT "   for X, Y, and Z."
630       PRINT "3. If you wish to enter an orientation angle,"
640       PRINT "   enter '-999,orientation,0'."
650       PRINT
660       !
670 Begin: !
680         Count=Count+1
690         PRINT "Item #";Count
700         INPUT "(X,Y,Z) in inches?",X(Count),Y(Count),Z(Count)
710         OUTPUT 701;"I,X,Y,Z=";Count,X(Count),Y(Count),Z(Count)
720         IF X(Count)<>-100 THEN GOTO Begin
730       !
740         End_count=Count-1
750         !
760         !  All data points have been entered.
770         !
780         !  a.  Set up new softkeys.
790         !  b.  Explain softkeys.
800         !
810     GOSUB Clear_screen
820     !
830     PRINT "SOFTKEY LABELS:"
840     PRINT "  0 -- WRITE data to disk."
850     PRINT "  2 -- EDIT out bad data."
860     PRINT "  4 -- HARD copy the data on printer."
870     PRINT "  6 -- LIST data on the CRT."
880     PRINT "  8 -- STOP terminates the program."
890     !
900     ON KEY 0 LABEL "WRITE" GOSUB Write_data
910     ON KEY 2 LABEL "EDIT" GOSUB Edit_data
920     ON KEY 4 LABEL "HARD" GOSUB Hard_copy
930     ON KEY 6 LABEL "LIST" GOSUB List_data
940     ON KEY 8 LABEL "STOP" GOTO Terminate
950     GOTO 900
960     !
970     !
980     !
990     !
1000    !
1010    !
1020    !
1030 Clear_screen:   !
1040        !
1050        !  Clear the CRT display.
1060        !
1070        OUTPUT 2 USING "#,B";255,75
1080        GCLEAR
1090 RETURN
1100    !
1110    !
1120    !
1130    !
1140    !
1150    !
1160 Hard_copy: !
1170        !
1180        ! Print out all data to the printer.
1190        !
1200        PRINTER IS 701
```

```
1210       !
1220         PRINT "  Count     X(inches)     Y(count)     Z(count)"
1230         PRINT "  _____     _________     ________     ________"
1240         PRINT
1250       FOR I=1 TO End_count
1260         PRINT I,X(I),Y(I),Z(I)
1270       NEXT I
1280       !
1290       PRINTER IS 1
1300 RETURN
1310 !
1320 !
1330 !
1340 !
1350 !
1360 !
1370 List_data: !
1380    !
1390    ! List data to the CRT.
1400    !
1410    GOSUB Clear_screen
1420    !
1430    PRINT "There are";End_count;" data points."
1440    PRINT
1450    INPUT "Which point do I start with?",Start
1460    INPUT "which point do I end with?",End_data
1470    !
1480    FOR I=Start TO End_data
1490       PRINT "I,X,Y,Z=";I,X(I),Y(I),Z(I)
1500    NEXT I
1510  RETURN
1520  !
1530  !
1540  !
1550  !
1560  !
1570  !
1580 Edit_data:  !
1590        !
1600        !  Edit data.
1610        !
1620        GOSUB Clear_screen
1630        !
1640        INPUT "Which data point do you wish to alter?",I
1650        !
1660        PRINT
1670        PRINT "For point #";I;", (X,Y,Z) where:"
1680        PRINT X(I);",";Y(I);",";Z(I)
1690        !
1700        INPUT "Type in the new values:",X(I),Y(I),Z(I)
1710  RETURN
1720  !
1730  !
1740  !
1750  !
1760  !
1770  !
1780 Write_data:  !
1790        !
1800        !  Write data out to a file on disk.
```

```
1810        !
1820        X(End_count+1)=-100
1830        Y(End_count+1)=-100
1840        Z(End_count+1)=-100
1850        !
1860        Max_data=3*(End_count+1)
1870        !
1880        File_size=INT(Max_data*8/256)+1
1890        !
1900        CREATE BDAT Filename$,File_size
1910        ASSIGN @File TO Filename$
1920        !
1930        FOR I=1 TO End_count+1
1940          OUTPUT @File;X(I),Y(I),Z(I)
1950        NEXT I
1960        !
1970        GOSUB Clear_screen
1980        BEEP 2400,.3
1990        PRINT "File ";Filename$;" has been stored!"
2000        ASSIGN @File TO *
2010  RETURN
2020  !
2030  !
2040  !
2050  !
2060  !
2070  !
2080 Terminate:  !
2090        GOSUB Clear_screen
2100        PRINT "NORMAL TERMINATION OF PROGRAM!"
2110  END
```

## 9. SEND_DATA

```
10    !    SEND_DATA
20    !
30    !    To VAX,IBM,TRS-80.
40    !
50    !  HP-9826 TERMINAL PROGRAM
60    !  [REQUIRES BINARY ENHANCEMENT PROGRAM
70    !   "BEB"!]
80    !
90    !  JUNE 30, 1982
100   !  updated 1/5/83
110   !  updated 1/16/84
120   !
130   !  BILL CULBRETH
140   !
150   !
160   Sc=9     ! RS-232 IS SELECT CODE 9.
170   PRINTER IS 1  ! PRINTER IS CRT.
180   Pr=1          ! DEFAULT PRINTER IS CRT
190   Printer_choice=701 ! MY PRINTER IS 701.
200   Bits=7        ! BITS PER CHARACTER
210   Duplex=0      ! FULL DUPLEX
220   Baud=300      ! BAUD RATE
230   Computer=1    ! ASSUME IBM COMPUTER
240   !
250   OUTPUT Pr;"{300 BAUD, IBM assumed."
260   OUTPUT Pr;" Load the binary program BEB first"
270   OUTPUT Pr;" unless you have BASIC 2.0"
280   OUTPUT Pr;" SET MODEM ON <FULL DUPLEX> }"
290   OUTPUT Pr;" "
300   !
310   DIM Name$[200],Hp_file$[30],Aa(1500),Numb$[30]
320   INTEGER Isend
330   !
340   CONTROL Sc,3;Baud
350   CONTROL Sc,4;Bits-5+4 ! BITS/CHAR & #STOP BITS.
360   !
370   !
380   To_disk=0
390   Datadump=0
400   I_data=1
410   I=1
420   J=1
430   K=1
440   L=1
450   !
460   ON ERROR GOTO Errors
470   ON KEY 0 LABEL "Line Mode" GOTO Line_mode
480   ON KEY 5 LABEL "Terminal" GOTO Terminal
490   ON KEY 6 LABEL "To Crt" GOTO Pr_crt
500   ON KEY 7 LABEL "To Prt" GOTO Pr_prt
510   ON KEY 8 LABEL "DATA" GOTO Data_dump
520   !
530   !
540 Line_mode:    !
550         OUTPUT Pr;"{LINE RECEPTION MODE}"
560 Begin: STATUS Sc,10;Y ! CHECK FOR FULL BUFFER
570
580         IF BIT(Y,0)=0 THEN GOTO Begin
590   !
600   !  RECEIVE ROUTINE.
```

```
610   !
620 Receive:      STATUS Sc,6;A
630         B=A
640         OUTPUT Pr USING "#,A";CHR$(B)
650         IF B=63 AND Datadump=1 THEN GOTO Data_dump
660         IF B=13 AND Computer=3 THEN OUTPUT Pr;CHR$(13)
670         GOTO Begin
680   !
690   !  TRANSMIT ROUTINE.
700   !
710*
720                IF Duplex=0 THEN
730                    IF NUM(Key$)<>255 THEN OUTPUT Pr USING "#,A";Key$
740                    IF NUM(Key$)=255 THEN OUTPUT Pr;" "
750                END IF
760                IF Computer=1 AND NUM(Key$)=8 THEN Key$=CHR$(64)
770                !
780                !  the previous line gives an @
790                !  for a backspace for the IBM.
800                !
810                IF Computer=5 AND NUM(Key$)=8 THEN Key$=CHR$(127)
820                !
830                !  THE VAX/VMS REQUIRES A DELETE
840                !  SYMBOL FOR A BACKSPACE.
850                !
860                IF NUM(Key$)=255 THEN Key$=CHR$(13)
870                OUTPUT Sc USING "#,A";Key$
880                GOTO Begin
890  !
900  !
910  !
920  !   DATA FILE OUT TO THE HOST COMPUTER.
930  !
940  !
950 . !
960 Data_dump:     !
970                IF I_data=1 THEN GOSUB Open_file
980                !
990                IF Datadump=0 THEN GOTO Begin
1000                   IF Computer=1 THEN WAIT .3
1010                   ! wait for the slow IBM.
1020                   BEEP 1000+RND*1500,.05
1030                   OUTPUT Pr;"A(";I_data;")=";
1040                   OUTPUT Pr;Aa(I_data)
1050                   GOSUB Send_number
1060               IF Aa(I_data)=-200 THEN
1070                       I_data=1
1080                       Datadump=0
1090               END IF
1100               I_data=I_data+1
1110 GOTO Begin
1120 !
1130 !
1140 !  ERROR HANDLING SUBROUTINE
1150 !
1160 Errors:  OFF ERROR
1170          Close_file=-200
1180          !  FIRST. END OF FILE ERROR.
1190          IF ERRN=59 THEN
1200              Aa(I)=-200
```

```
1210              GOTO 2000 ! RETURN AFTER ERROR.
1220           END IF
1230           !
1240           IF ERRN<>59 THEN OUTPUT Pr;"<error #";ERRN;" generated.>"
1250           IF ERRN=54 THEN OUTPUT Pr;"(FILE <";Hp_file$;"> ALREADY THERE)"
1260           IF ERRN=54 THEN GOTO Created
1270           IF ERRN=56 THEN OUTPUT Pr;"<FILE (";Hp_file$;" IS NOT ON DISK.>"
1280           ASSIGN @File TO *
1290 GOTO Line_mode
1300 !
1310 !
1320 !  OUTPUT TO CRT.
1330 !
1340 Pr_crt:  Pr=1
1350          GOTO Line_mode
1360 !
1370 !
1380 !  OUTPUT TO PRINTER.
1390 !
1400 Pr_prt:  Pr=Printer_choice
1410 GOTO Line_mode
1420 !
1430 !
1440 !  CHANGE THE TERMINAL CHARACTERISTICS.
1450 !
1460 Terminal:  !
1470             OUTPUT Pr;"     1.  Baud Rate =";Baud
1480             OUTPUT Pr;"     2.  Bits/Char =";Bits
1490             OUTPUT Pr;"     3.  Duplex    =";Duplex
1500             OUTPUT Pr;"         [1=full,0=half]"
1510             OUTPUT Pr;"     4.  Computer  =";Computer
1520             OUTPUT Pr;"         [IBM=1, VAX/UNIX=2, "
1530             OUTPUT Pr;"          TRS-80=3, Cyber=4, vax/vms=5]"
1540             OUTPUT Pr;" "
1550             INPUT "Change which one?",Which
1560             IF Which=1 THEN INPUT "To?",Baud
1570             IF Which=2 THEN INPUT "To?",Bits
1580             IF Which=3 THEN INPUT "To?",Duplex
1590             IF Which=4 THEN INPUT "To?",Computer
1600             IF Computer=1 THEN Duplex=0
1610             IF Computer=3 THEN Duplex=0
1620             IF Computer=3 THEN Bits=8
1630             IF Computer=5 THEN Duplex=1
1640 GOTO Line_mode
1650 !
1660 !
1670 !
1680 Open_file:  !
1690             !  Open a file to read data from
1700             !  disk.
1710             !
1720     Datadump=1
1730     !
1740       INPUT "Is this LDV data? (1=YES)",Ldv$
1750       IF Ldv$="1" THEN
1760         INPUT "Experiment #?",Experiment$
1770       ELSE
1780         OUTPUT Pr;"Data file out of HP to host."
1790         INPUT "File name?",Hp_file$
1800       END IF
```

```
1810       !
1820       IF Ldv$="1" THEN
1830         Hp_file$=Experiment$&"_RESULT"
1840       END IF
1850       !
1860       !  Read the file off of disk.
1870       !
1880       ASSIGN @File TO Hp_file$
1890       I=1
1900       Check=0
1910       BEEP
1920       BEEP
1930       OUTPUT Pr;"{Working on file <";Hp_file$;">.}"
1940       !
1950*
1960         ENTER @File;Aa(I)
1970         Check=Aa(I)
1980         I=I+1
1990*
2000       !
2010       ASSIGN @File TO *
2020         Datadump=1
2030 RETURN
2040 !
2050 !
2060 !
2070 Send_number: !
2080              ! SEND A NUMBER ONE CHARACTER AT
2090              ! A TIME TO THE HOST COMPUTER.
2100              !
2110          Numb$=VAL$(Aa(I_data))
2120          Length=LEN(Numb$)
2130          !
2140          IF ((Ldv$="1") AND (I_data>13)) THEN
2150            Posit=POS(Numb$,".")
2160            IF (Posit<>0) THEN Length=Posit+2
2170          END IF
2180          !
2190          FOR I=1 TO Length
2200            Numeric=NUM(Numb$[I,I])
2210            OUTPUT Sc USING "#,A";Numb$[I,I]
2220          NEXT I
2230          !
2240          OUTPUT Sc USING "#,A";CHR$(13)
2250 RETURN
2260 !
2270 !
2280 !
2290 END
```

APPENDIX C

MAINFRAME PROGRAMS

## 1. TCAL

```
C
C
C     TCAL
C
C     PURPOSE:  THIS PROGRAM PLACES THERMOCOUPLE CALIBRATION DATA
C               RECEIVED FROM THE HP-9826 MICROCOMPUTER INTO A
C               MORE WORKABLE FORMAT FOR USE IN THE PROGRAM TFIT.
C
C
      DIMENSION TPROBE(200),TAMB(200),TNOZZ(200)
      I=1
   10 READ(07,*) TAMB(I)
      IF(TAMB(I).EQ.-200.0) GO TO 20
      READ(07,*) TPROBE(I)
      READ(07,*) TNOZZ(I)
      NITEMS=I
      I=I+1
      GO TO 10
   20 CONTINUE
      WRITE(6,40)
      DO 30 I=1,NITEMS
         WRITE(6,50)I,TAMB(I),TPROBE(I),TNOZZ(I)
   30 CONTINUE
   40 FORMAT(8X,'AMBIENT (C)',2X,'PROBE (C)',2X,'NOZZLE (C)')
   50 FORMAT(1X,I3,6X,2(F6.3,6X))
      STOP
      END
```

2. TFIT

```
C
C     TFIT
C
C     PURPOSE:   THIS PROGRAM PERFORMS A FIRST ORDER CURVE FIT BY THE
C                LEAST SQUARES METHOD FOR TWO COLUMNS OF DATA.  THE
C                FIRST COLUMN LISTS VALUES OF X AND THE SECOND LISTS
C                VALUES OF F(X) OR Y.  FOR THERMOCOUPLE CALIBRATION,
C                LET X = THE AMBIENT TEMPERATURE, AND LET Y = EITHER
C                THE PROBE OR NOZZLE TEMPERATURE AS DESIRED.
C
      DIMENSION X(150),Y(150),XSQ(150),XY(150),YEST(150)
      SUMX=0.0
      SUMXSQ=0.0
      SUMXY=0.0
      SUMY=0.0
      SUMNUM=0.0
      SUMDEN=0.0
      READ(7,*)NITEMS
      DO 10 I=1,NITEMS
         READ(7,*)X(I),Y(I)
         XSQ(I)=X(I)**2
         XY(I)=X(I)*Y(I)
         SUMX=SUMX+X(I)
         SUMXSQ=SUMXSQ+XSQ(I)
         SUMXY=SUMXY+XY(I)
         SUMY=SUMY+Y(I)
   10 CONTINUE
      XITEMS=FLOAT(NITEMS)
      A=(SUMY*SUMXSQ-SUMX*SUMXY)/(XITEMS*SUMXSQ-SUMX**2)
      B=(XITEMS*SUMXY-SUMX*SUMY)/(XITEMS*SUMXSQ-SUMX**2)
      YBAR=SUMY/XITEMS
      DO 20 I=1,NITEMS
         YEST(I)=B*X(I)+A
      WRITE(6,*)YEST(I), Y(I)
         SUMNUM=SUMNUM+(YEST(I)-YBAR)**2
         SUMDEN=SUMDEN+(Y(I)-YBAR)**2
   20 CONTINUE
      RSQ=SUMNUM/SUMDEN
      WRITE(6,*)A,B,RSQ
      STOP
      END
```

3. JETCURV

```
C
C     JETCURV
C
C
C     PURPOSE:   THIS PROGRAM FITS JET TRAJECTORY DATA TO THE EQUATION
C                Z=A*Y/(B+Y) BY THE LEAST SQUARES METHOD AND COMPUTES A
C                CORROLATION COEFFICIENT (R**2).  DATA POINTS ARE READ
C                IN FREE FORMAT FROM UNIT "7" DISK.
C
C
      DIMENSION Y(50),Z(50),YY(50),ZZ(50),YSQ(50),YZ(50),ZEST(50)
      SUMY=0.0
      SUMYSQ=0.0
      SUMYZ=0.0
      SUMZ=0.0
      SUMNUM=0.0
      SUMDEN=0.0
      READ(7,*)NITEMS,FACTOR
      DO 10 I=1,NITEMS
         READ(7,*)Y(I),Z(I)
         Y(I)=Y(I)/FACTOR
         YY(I)=1.0/Y(I)
         ZZ(I)=1.0/(Z(I)/FACTOR)
         YSQ(I)=YY(I)**2
         YZ(I)=YY(I)*ZZ(I)
         SUMY=SUMY+YY(I)
         SUMYSQ=SUMYSQ+YSQ(I)
         SUMYZ=SUMYZ+YZ(I)
         SUMZ=SUMZ+ZZ(I)
   10 CONTINUE
      XITEMS=FLOAT(NITEMS)
      AA=(SUMZ*SUMYSQ-SUMY*SUMYZ)/(XITEMS*SUMYSQ-SUMY**2)
      BB=(XITEMS*SUMYZ-SUMY*SUMZ)/(XITEMS*SUMYSQ-SUMY**2)
      A=1.0/AA
      B=A*BB
      ZBAR=SUMZ/XITEMS
      DO 20 I=1,NITEMS
         ZEST(I)=BB*YY(I)+AA
         WRITE(6,30)ZZ(I),ZEST(I)
         SUMNUM=SUMNUM+(ZEST(I)-ZBAR)**2
         SUMDEN=SUMDEN+(ZZ(I)-ZBAR)**2
   20 CONTINUE
      RSQ=SUMNUM/SUMDEN
      WRITE(6,40)A,B,RSQ
   30 FORMAT(1X,'Z (ACTUAL) =',F12.8,3X,'Z (EST) =',F12.8)
   40 FORMAT(1X,'A= ',F12.8,2X,'B= ',F12.8,2X,'R**2= ',F12.8)
      STOP
      END
```

4. GRAB

```
C
C       GRAB
C
C       PURPOSE:  DATA TRANSFER FROM THE HP-9826MICROCOMPUTOR
C       TO THE IBM.
C
C       BY BILL CULBRETH
C       FOR ME2410, FALL QUARTER, 1982
C
C       FILEDEF 05 TERMINAL
C       FILEDEF 06 TERMINAL
C       FILEDEF 07 DISK MYDATA DATA (PERM)
C
C       GLOBAL TXTLIB FORTMOD2 MOD2EEH
C
C             TYPE IN THE ABOVE 4 LINES TO MAKE THIS
C                   FORTRAN PROGRAM RUN.
C
C
        DIMENSION DATA(3000)
        I=1
        WRITE(6,80)
80      FORMAT(2X,'BEGIN INPUTING DATA FROM THE HP-9826')
C
C
10      CONTINUE
        READ(5,*) DATA(I)
        I=I+1
        IF(DATA(I-1).NE.-200) GOTO 10
C
        NITEMS = I-1
6       FORMAT(2X,I5,'  DATA POINTS WERE ENTERED.')
        WRITE(6,6) NITEMS
C
C       NOW THAT ALL DATA HAS BEEN ENTERED, WRITE IT OUT ON
C       DISK.
C
5       FORMAT(2X,'DATA(',I5,') = ',IF15.5)
        I=1
20      WRITE(7,*) DATA(I)
        I=I+1
        IF(DATA(I-1).NE.-200) GOTO 20
C
C             ALL DATA HAS BEEN WRITTEN ONTO DISK.
C
        STOP
        END
```

## 5. TDATA

```
C
C
C     TDATA
C
C     PURPOSE:   THIS PROGRAM PLACES THE BUOYANT JET DATA RECEIVED
C                FROM THE HP-9826 MICROCOMPUTER INTO A MORE ORDERLY
C                FORMAT.  IT ALSO CONVERTS UNITS OF LENGTH FROM SI
C                TO METRIC.
C
      DIMENSION X(200),Y(200),Z(200),TPROBE(200),TAMB(200),TNOZZ(200),
     1STDEV(200),XMM(200),YMM(200),ZMM(200)
      I=1
   10 READ(07,*) X(I)
      IF(X(I).EQ.-200.0) GO TO 20
      XMM(I)=25.4*X(I)
      READ(07,*) Y(I)
      YMM(I)=25.4*Y(I)
      READ(07,*) Z(I)
      ZMM(I)=25.4*Z(I)
      READ(07,*) TPROBE(I)
      READ(07,*) TAMB(I)
      READ(07,*) TNOZZ(I)
      READ(07,*) STDEV(I)
      NITEMS=I
      I=I+1
      GO TO 10
   20 CONTINUE
      WRITE(6,40)
      DO 30 I=1,NITEMS
         WRITE(6,50)I,XMM(I),YMM(I),ZMM(I),TPROBE(I),TAMB(I),TNOZZ(I),
     1STDEV(I)
   30 CONTINUE
   40 FORMAT(8X,'X (MM)',4X,'Y (MM)',4X,'Z (MM)',2X,'PROBE (C)',1X,
     1'AMBIENT (C)',1X,'NOZZLE (C)',1X,'STD DEV (C)')
   50 FORMAT(1X,I3,3X,2(F7.3,3X),F7.3,4X,4(F6.3,4X))
      STOP
      END
```

## 6. CONTOUR4

```
C
C       CONTOUR4
C
C
C       PURPOSE:    THIS PROGRAM IS DESIGNED TO DISPLAY BUOYANT JET
C                   TEMPERATURE DATA USING A CONTOUR PLOTTING PACKAGE
C                   AVAILABLE WITH DISSPLA.  THE FOLLOWING RAW DATA IS
C                   READ FROM A DISK FILE: PROBE POSITIONS IN XYZ
C                   COORDINATES RELATIVE TO THE NOZZLE TIP, AMBIENT
C                   TEMPERATURE, PROBE TEMPERATURE AND NOZZLE TEMPERATURE.
C                   THE PROBE AND NOZZLE TEMPERATURES ARE TRANSFORMED
C                   BY CALIBRATION COEFFICIENTS AND NORMALIZED WRT AMBIENT
C                   TEMPERATURE.  THE XYZ COORDINATES ARE CONVERTED TO
C                   XSW COORDINATES RELATIVE TO THE INTERSECTION OF THE
C                   DATA PLANE WITH THE CENTERLINE TRAJECTORY OF THE JET
C                   (THE S-AXIS IS TANGENT TO THE TRAJECTORY).  THIS
C                   PROGRAM ALSO COMPUTES THE RATE OF HEAT TRANSFER FROM
C                   THE JET TO THE AMBIENT.
C
C                   NOTE:  THE FOLLOWING VALUES MUST BE INSERTED AS THE
C                   FIRST LINE OF DATA IN FREE FORMAT: THE TOTAL NUMBER
C                   OF DATA POINTS (NITEMS), THE ACUTE ANGLE BETWEEN
C                   THE DATA PLANE AND HORIZONTAL (THETA) AND THE VERTICAL
C                   DISTANCE BETWEEN THE Z-AXIS AND THE INTERSECTION
C                   POINT DISCUSSED ABOVE (ZA), THE CENTERLINE VELOCITY
C                   IN M/S (VEL) AND JET WIDTH IN MM (WIDTH).
C
C
      DIMENSION X(100),Y(100),T(100),TP(100),TA(100),TN(100),TMAT(10,10)
      COMMON WORK(16000)
C
C
C* * * * READ DATA FROM UNIT "7" DISK * * * *
C
C
      READ(7,*)  NITEMS,THETA,ZA,VEL,WIDTH
C
      DO 20 I=1,NITEMS
         READ(7,*)  A,X(I),A,Y(I),TP(I),TA(I),TN(I),A
            Y(I) = (Y(I)-ZA)/SIN(THETA)
C
C                          CALIBRATION COEFFICIENTS
            TP(I)=.984809875*TP(I)+1.74079605
            TN(I)=.933223426*TN(I)+1.84754086
C
            T(I) = (TP(I) - TA(I))/(TN(I) - TA(I))
   20 CONTINUE
C
C  30 FORMAT(2X,'I,X,Y,T=',I5,3F15.5)
C
C
C* * * * DIMENSION OF TMAT * * * *
C
C
      IXDIM = 10
      IYDIM = 10
C
C
C
C* * * * FIND THE MAXIMUM AND MINIMUM TEMPERATURES * * * *
C
C
      TMIN = 100.0
      TMAX = 0.0
      XMAX=0.0
      YMAX=0.0
      XMIN=100.0
      YMIN=100.0
C
      DO 40 I=1,NITEMS
         IF(T(I) .GT. TMAX)   TMAX = T(I)
         IF(T(I) .LT. TMIN)   TMIN = T(I)
```

```
      IF(X(I).GT.XMAX)XMAX=X(I)
      IF(Y(I).GT.YMAX)YMAX=Y(I)
      IF(X(I).LT.XMIN)XMIN=X(I)
      IF(Y(I).LT.YMIN)YMIN=Y(I)
   40 CONTINUE
C
C* * * * DETERMINE THE MAXIMUM VALUES OF X AND Y WITHIN A
C        QUADRANT, ASSUMING THE STREAMWISE AXIS IS CENTERED
C        IN A SQUARE MATRIX PLANE
C
      DX=((XMAX-XMIN)/FLOAT(IXDIM))/1000.
      DY=((YMAX-YMIN)/FLOAT(IYDIM))/1000.
      QUADX=(FLOAT(IXDIM)/2.0)*DX
      QUADY=(FLOAT(IYDIM)/2.0)*DY
C
C* * * * FIND THE INCREMENTAL AREA FOR HEAT TRANSFER CALCULATIONS * * *
C
      AREA=DX*DY
C
C* * * * ESTABLISH THE INCREMENT SIZE FOR CONTOUR PLOTS * * * *
C
      TINCR=(TMAX-TMIN)/5.25
C
C
C* * * * GENERATE THE GRID * * * *
C
C
      CALL COMPRS
C     CALL TEK618
      CALL PAGE( 8.,9.)
      CALL BLOWUP (0.75)
      CALL PHYSOR(1.25,1.)
      CALL AREA2D(5.5,5.5)
C
      CALL HEIGHT(0.100)
      CALL CARTOG
      CALL INTAXS
      CALL XNAME('X (MM)$',100)
      CALL YNAME('W (MM)$',100)
           CALL XTICKS(2)
           CALL YTICKS(2)
           CALL YAXANG(90.0)
C
C
C
      CALL SWISSM
      CALL HEADIN('TEMPERATURE CONTOURS IN A BUOYANT JET$',100,2.,4)
      CALL HEADIN('WITH A CROSSFLOWING AMBIENT$',100,2.,4)
      CALL HEADIN('(25% FLOW RATE)$',100,1.,4)
      CALL HEADIN('(PLANE A)$',100,1.,4)
      CALL GRAF(-30.0,05.0,30.0,-30.0,05.0,30.0)
C
C* * * * GENERATE THE INTERPOLATED TEMPERATURE MATRIX "TMAT" * * *
C
      CALL BCOMON(10000)
      CALL ZBASE(TMIN)
         CALL BGNMAT(IXDIM,IYDIM)
         CALL GETMAT(X,Y,T,NITEMS,0)
         CALL ENDMAT(TMAT,0)
C
C* * * * SOLVE THE RATE OF HEAT TRANSFER * * * *
C
         QSUM=0.0
         DO 70 I=1,IXDIM
              DO 60 J=1,IYDIM
                   RO=(1.0000433 + 3.5191E-5*TMAT(I,J)
     1             -6.9562667E-6*TMAT(I,J)**2
     1             + 3.4129629E-8*TMAT(I,J)**3
     1             -9.740676E-11*TMAT(I,J)**4)*1000.
                   XX=QUADX-FLOAT(J-1)*DX
                   YY=QUADY-FLOAT(I-1)*DY
                   RADIUS=SQRT(XX**2 + YY**2)
```

```
                  V=VEL*EXP(-RADIUS**2/WIDTH**2)
                  Q=RO*AREA*V*.445*(TMAT(I.J)+273.16)
                  QSUM=QSUM+Q
   60          CONTINUE
   70      CONTINUE
           WRITE(6.80)QSUM
   80      FORMAT(1X.'Q=  '.F20.5)
C
C* * * * PLOT THE CONTOURS * * * *
C
         CALL CONMAK(TMAT.IXDIM.IYDIM.TINCR)
         CALL CONLIN(0.'SOLIDS'.'LABELS'.1.10)
         CALL CONANG(90.0)
         CALL RASPLN(0.25)
         CALL CONTUR(1.'LABELS'.'DRAW')
         CALL HEIGHT (0.05)
         CALL RLMESS('EXP 1C $'.100.-59.-59)
         CALL DOT
         CALL GRID(1.1)
         CALL ENDPL(0)
         CALL DONEPL
         STOP
         END
```

APPENDIX D

TABULATED DATA

TABLE 1

ROTOMETER CALIBRATION

| % Flow | ml/s | Std Dev (ml/s) |
|---|---|---|
| 10 | 5.94 | 0.32 |
| 15 | 8.02 | 0.56 |
| 20 | 10.05 | 0.41 |
| 25 | 11.85 | 0.24 |
| 30 | 14.03 | 0.33 |
| 35 | 15.98 | 0.58 |
| 40 | 17.41 | 0.31 |
| 45 | 19.09 | 0.34 |
| 50 | 20.75 | 0.23 |
| 55 | 22.38 | 0.28 |
| 60 | 24.27 | 0.22 |
| 65 | 26.03 | 0.20 |
| 70 | 27.64 | 0.37 |
| 75 | 29.53 | 0.24 |

TABLE 2

TEST RESULTS

| | |
|---|---|
| Crossflow velocity: | .13 m/s |
| Nozzle flow rate: | 11.85 ml/s (25%) |
| Nozzle inside diameter: | 7.144 mm |
| Nozzle discharge velocity (mean): | 29.558 mm/s |
| Nozzle temperature (mean): | 41.8 °C |
| Ambient temperature (mean): | 24.9 °C |
| Froude number: | 14.8 |
| Michaelis-Menter equation: | |
| Coefficient A: | 2.64284325 |
| Coefficient B: | 1.03698254 |

| Plane | Y (mm) | $\phi$ (degrees) | $\dot{Q}$ (W) |
|---|---|---|---|
| A | 7.327 | 46 | 1.20 |
| B | 21.370 | 58 | 6.392 |
| C | 39.688 | 70 | 15.349 |
| D | 62.889 | 80 | 18.388 |
| E | 87.313 | 86 | 27.628 |

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Thesis
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